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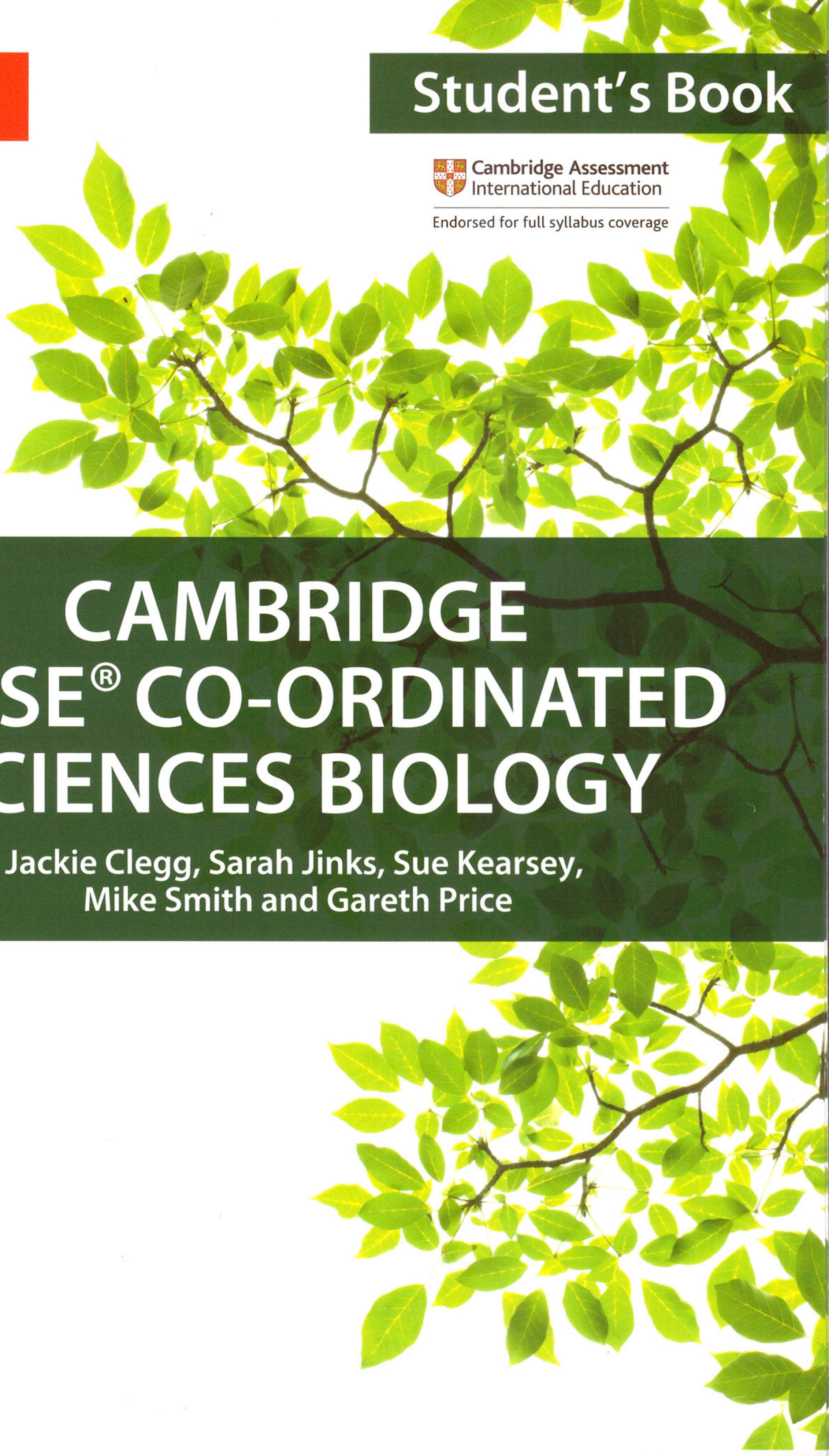

CAMBRIDGE IGCSE® CO-ORDINATED SCIENCES BIOLOGY

Jackie Clegg, Sarah Jinks, Sue Kearsey,
Mike Smith and Gareth Price

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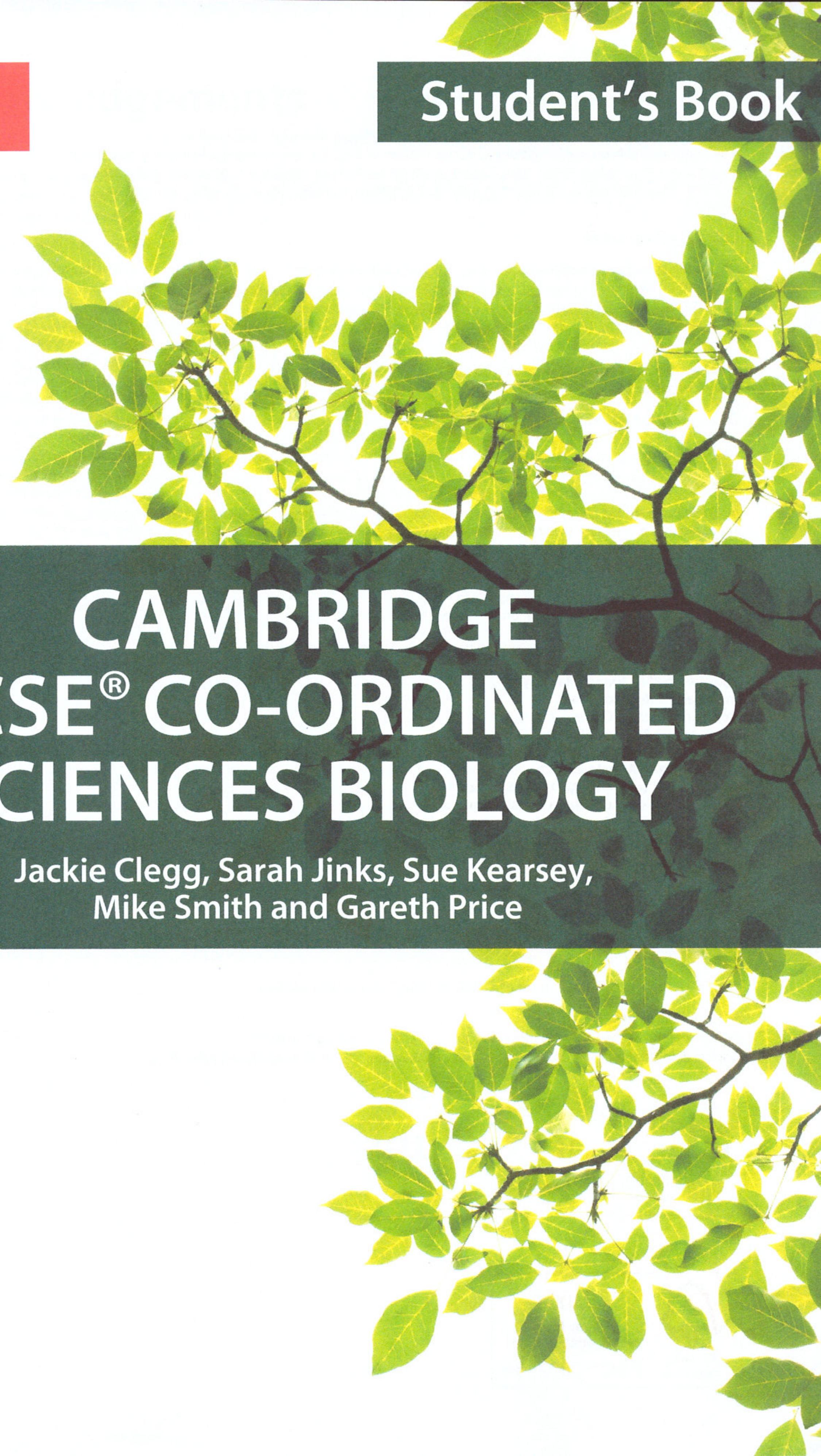

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1st Floor, Watermarque Building, Ringsend Road
Dublin 4, Ireland

Browse the complete Collins catalogue at
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10 9 8 7 6 5 4

ISBN 978-0-00-819157-3

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British Library Cataloguing in Publication Data
A catalogue record for this publication is available from the British Library.

Original material by **Jackie Clegg, Sue Kearsey, Mike Smith and Gareth Price**
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Commissioned by **Joanna Ramsay**
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Project managed by **Catharine Tucker**
Developed by **Amanda Harman**
Proofread by **Anna Clark**
Cover design by **Angela English**
Cover artwork by **CHAIWATPHOTOS/iStock**
Internal design by **Jouve India Private Limited**
Typesetting by **QBS Media Services Private Limited**
Illustrations by **Jouve India Private Limited and QBS Media Services Private Limited**
Production by **Lauren Crisp**

Printed and bound in the UK using 100% Renewable
Electricity at CPI Group (UK) Ltd

All exam-style questions and sample answers have been written by the author. In examinations marks may be given differently.

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Getting the best from the book

Welcome to Collins *Cambridge IGCSE Co-ordinated Sciences Biology*.

This textbook has been designed to help you understand all of the requirements of the Biology section of the Cambridge IGCSE Co-ordinated Sciences course.

SAFETY IN THE SCIENCE LESSON

This book is a textbook, not a laboratory or practical manual. As such, you should not interpret any information in this book that relates to practical work as including comprehensive safety instructions. Your teachers will provide full guidance for practical work and cover rules that are specific to your school.

A brief introduction to the section to give context to the science covered in the section.

The section contents shows the separate topics to be studied matching the syllabus order.

5

Plant nutrition

The world's tallest known living tree, which has been named Hyperion, is a coast redwood tree growing in Northern California in the US. When it was measured in 2006 it was found to be 115.61 m tall (379.3 ft). Like all plants, from the smallest seedling to the tallest redwood giant, Hyperion makes its own food from three simple ingredients, sunlight, water and carbon dioxide. This process is known as photosynthesis, and is one of the features of plants that distinguish them from animals.

CONTENTS

a) Photosynthesis

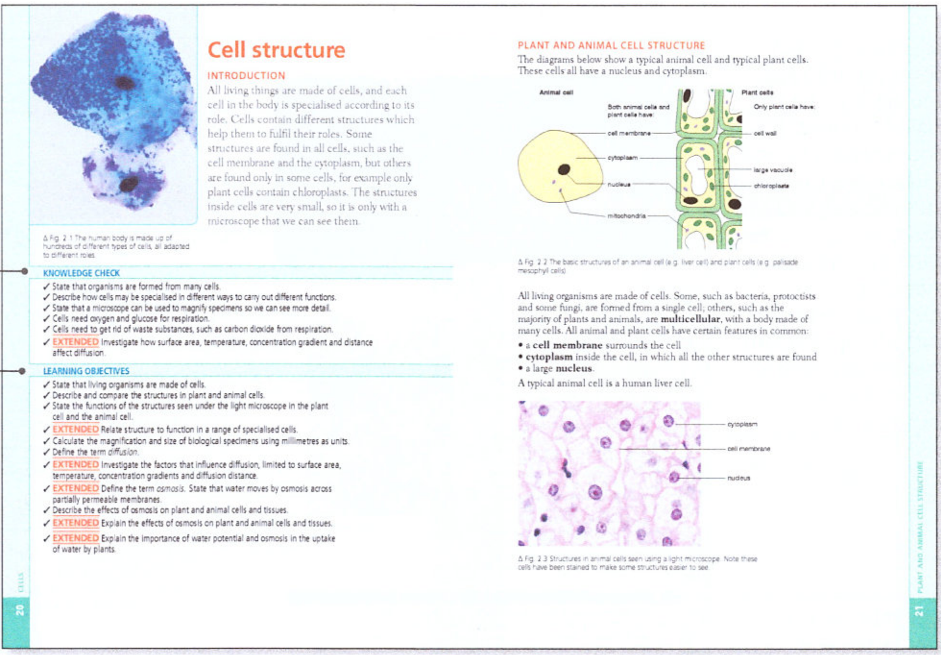
b) Leaf structure

c) Mineral requirements of plants

Δ Saplings growing toward a controlled light source.

Knowledge check shows the ideas you should have already encountered in previous work before starting the topic.

Learning objectives cover what you need to learn in this topic.



Cell structure

INTRODUCTION

All living things are made of cells, and each cell in the body is specialised according to its role. Cells contain different structures which help them to fulfil their roles. Some structures are found in all cells, such as the cell membrane and the cytoplasm, but others are found only in some cells, for example only plant cells contain chloroplasts. The structures inside cells are very small, so it is only with a microscope that we can see them.

Δ Fig. 2.1 The human body is made up of hundreds of different types of cells, all adapted to different roles.

KNOWLEDGE CHECK

- ✓ State that organisms are formed from many cells.
- ✓ Describe how cells may be specialised in different ways to carry out different functions.
- ✓ State that a microscope can be used to magnify specimens so we can see more detail.
- ✓ Cells need oxygen and glucose for respiration.
- ✓ Cells need to get rid of waste substances, such as carbon dioxide from respiration.
- ✓ EXTENDED Investigate how surface area, temperature, concentration gradient and distance affect diffusion.

LEARNING OBJECTIVES

- ✓ State that living organisms are made of cells.
- ✓ Describe and compare the structures in plant and animal cells.
- ✓ State the functions of the structures seen under the light microscope in the plant cell and the animal cell.
- ✓ EXTENDED Relate structure to function in a range of specialised cells.
- ✓ Calculate the magnification and size of biological specimens using millimetres as units.
- ✓ Define the term *diffusion*.
- ✓ EXTENDED Investigate the factors that influence diffusion, limited to surface area, temperature, concentration gradients and diffusion distance.
- ✓ EXTENDED Define the term *osmosis*. State that water moves by osmosis across partially permeable membranes.
- ✓ Describe the effects of osmosis on plant and animal cells and tissues.
- ✓ EXTENDED Explain the effects of osmosis on plant and animal cells and tissues.
- ✓ EXTENDED Explain the importance of water potential and osmosis in the uptake of water by plants.

CELLS 20

PLANT AND ANIMAL CELL STRUCTURE

The diagrams below show a typical animal cell and typical plant cells. These cells all have a nucleus and cytoplasm.

Δ Fig. 2.2 The basic structures of an animal cell (e.g. liver cell) and plant cells (e.g. palisade mesophyll cells)

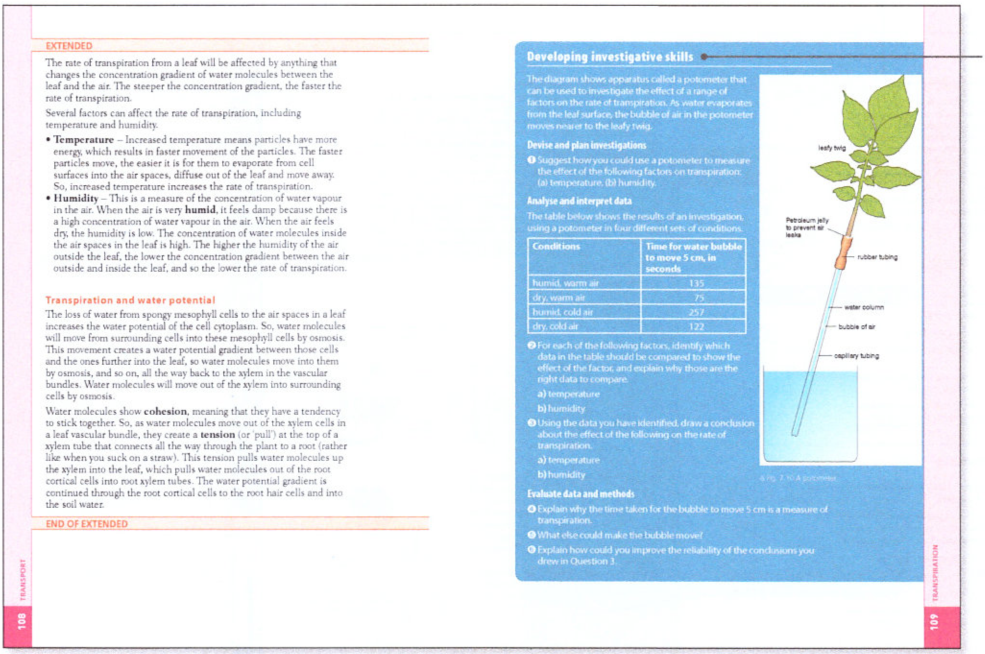
All living organisms are made of cells. Some, such as bacteria, protoctists and some fungi, are formed from a single cell; others, such as the majority of plants and animals, are **multicellular**, with a body made of many cells. All animal and plant cells have certain features in common:

- a **cell membrane** surrounds the cell
- **cytoplasm** inside the cell, in which all the other structures are found
- a large **nucleus**.

A typical animal cell is a human liver cell.

Δ Fig. 2.3 Structures in animal cells seen using a light microscope. Note these cells have been stained to make some structures easier to see.

PLANT AND ANIMAL CELL STRUCTURE 21



EXTENDED

The rate of transpiration from a leaf will be affected by anything that changes the concentration gradient of water molecules between the leaf and the air. The steeper the concentration gradient, the faster the rate of transpiration.

Several factors can affect the rate of transpiration, including temperature and humidity.

- **Temperature** – Increased temperature means particles have more energy, which results in faster movement of the particles. The faster particles move, the easier it is for them to evaporate from cell surfaces into the air spaces, diffuse out of the leaf and move away. So, increased temperature increases the rate of transpiration.
- **Humidity** – This is a measure of the concentration of water vapour in the air. When the air is very **humid**, it feels damp because there is a high concentration of water vapour in the air. When the air feels dry, the humidity is low. The concentration of water molecules inside the air spaces in the leaf is high. The higher the humidity of the air outside the leaf, the lower the concentration gradient between the air outside and inside the leaf, and so the lower the rate of transpiration.

Transpiration and water potential

The loss of water from spongy mesophyll cells to the air spaces in a leaf increases the water potential of the cell cytoplasm. So, water molecules will move from surrounding cells into these mesophyll cells by osmosis. This movement creates a water potential gradient between those cells and the ones further into the leaf, so water molecules move into them by osmosis, and so on, all the way back to the xylem in the vascular bundles. Water molecules will move out of the xylem into surrounding cells by osmosis.

Water molecules show **cohesion**, meaning that they have a tendency to stick together. So, as water molecules move out of the xylem cells in a leaf vascular bundle, they create a **tension** (or 'pull') at the top of a xylem tube that connects all the way through the plant to a root (rather like when you suck on a straw). This tension pulls water molecules up the xylem into the leaf, which pulls water molecules out of the root cortical cells into root xylem tubes. The water potential gradient is continued through the root cortical cells to the root hair cells and into the soil water.

END OF EXTENDED

TRANSPORT 108

Developing investigative skills

The diagram shows apparatus called a potometer that can be used to investigate the effect of a range of factors on the rate of transpiration. As water evaporates from the leaf surface, the bubble of air in the potometer moves nearer to the leafy twig.

Devise and plan investigations

❶ Suggest how you could use a potometer to measure the effect of the following factors on transpiration: (a) temperature, (b) humidity.

Analyse and interpret data

The table below shows the results of an investigation, using a potometer in four different sets of conditions.

Conditions	Time for water bubble to move 5 cm, in seconds
humid, warm air	135
dry, warm air	75
humid, cold air	257
dry, cold air	122

❷ For each of the following factors, identify which data in the table should be compared to show the effect of the factor, and explain why those are the right data to compare.

a) temperature
b) humidity

❸ Using the data you have identified, draw a conclusion about the effect of the following on the rate of transpiration.

a) temperature
b) humidity

Δ Fig. 7.10 A potometer

Evaluate data and methods

❹ Explain why the time taken for the bubble to move 5 cm is a measure of transpiration.

❺ What else could make the bubble move?

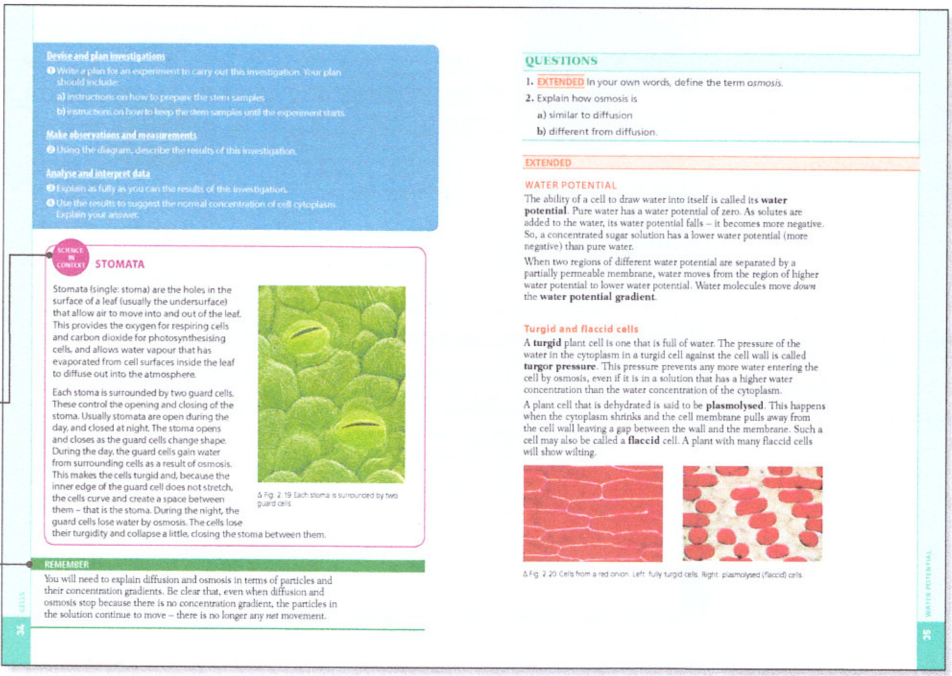
❻ Explain how could you improve the reliability of the conclusions you drew in Question 3.

TRANSPIRATION 109

Examples of investigations are included with questions matched to the investigative skills you will need to learn.

Getting the best from the book *continued*

Science in context boxes put the ideas you are learning into real-life context. It is not necessary for you to learn the content of these boxes as they do not form part of the syllabus. However, they do provide interesting examples of scientific applications that are designed to enhance your understanding.



Devise and plan investigations

❶ Write a plan for an experiment to carry out this investigation. Your plan should include:

a) instructions on how to prepare the stem samples

b) instructions on how to keep the stem samples until the experiment starts.

Make observations and measurements

❷ Using the diagram, describe the results of this investigation.

Analyse and interpret data

❸ Explain as fully as you can the results of this investigation.

❹ Use the results to suggest the normal concentration of cell cytoplasm. Explain your answer.

SCIENCE IN CONTEXT **STOMATA**

Stomata (single: stoma) are the holes in the surface of a leaf (usually the undersurface) that allow air to move into and out of the leaf. This provides the oxygen for respiring cells and carbon dioxide for photosynthesising cells, and allows water vapour that has evaporated from cell surfaces inside the leaf to diffuse out into the atmosphere.

Each stoma is surrounded by two guard cells. These control the opening and closing of the stoma. Usually stomata are open during the day, and closed at night. The stoma opens and closes as the guard cells change shape. During the day, the guard cells gain water from surrounding cells as a result of osmosis. This makes the cells turgid and, because the inner edge of the guard cell does not stretch, the cells curve and create a space between them – that is the stoma. During the night, the guard cells lose water by osmosis. The cells lose their turgidity and collapse a little, closing the stoma between them.

Δ Fig. 2.19 Each stoma is surrounded by two guard cells.

REMEMBER

You will need to explain diffusion and osmosis in terms of particles and their concentration gradients. Be clear that, even when diffusion and osmosis stop because there is no concentration gradient, the particles in the solution continue to move – there is no longer any *net* movement.

QUESTIONS

1. EXTENDED In your own words, define the term *osmosis*.
2. Explain how osmosis is
   a) similar to diffusion
   b) different from diffusion.

EXTENDED

WATER POTENTIAL

The ability of a cell to draw water into itself is called its **water potential**. Pure water has a water potential of zero. As solutes are added to the water, its water potential falls – it becomes more negative. So, a concentrated sugar solution has a lower water potential (more negative) than pure water.

When two regions of different water potential are separated by a partially permeable membrane, water moves from the region of higher water potential to lower water potential. Water molecules move *down* the **water potential gradient**.

Turgid and flaccid cells

A **turgid** plant cell is one that is full of water. The pressure of the water in the cytoplasm in a turgid cell against the cell wall is called **turgor pressure**. This pressure prevents any more water entering the cell by osmosis, even if it is in a solution that has a higher water concentration than the water concentration of the cytoplasm.

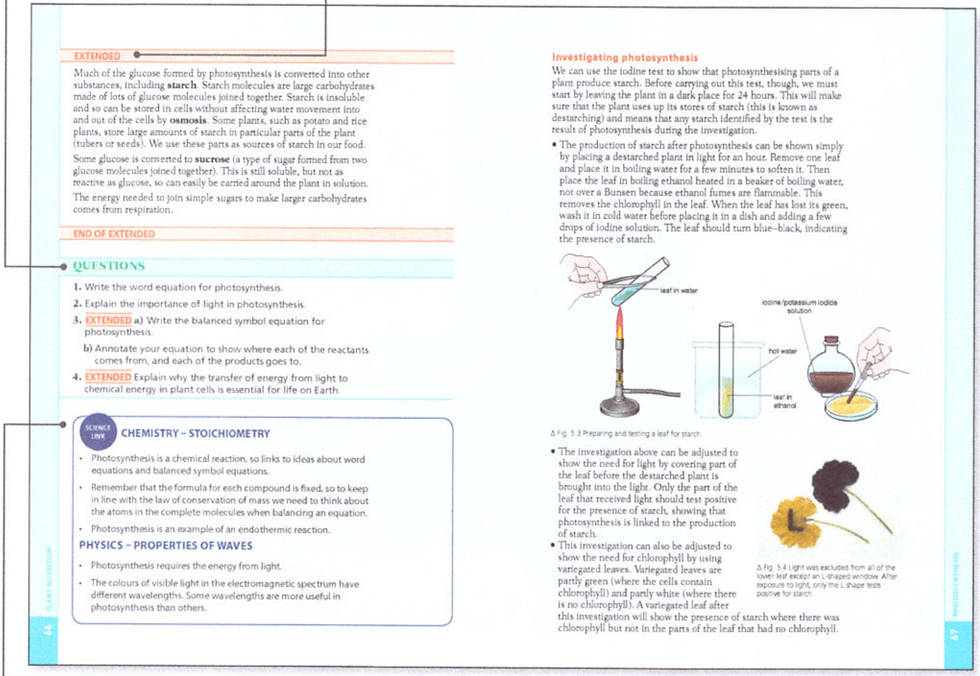
A plant cell that is dehydrated is said to be **plasmolysed**. This happens when the cytoplasm shrinks and the cell membrane pulls away from the cell wall leaving a gap between the wall and the membrane. Such a cell may also be called a **flaccid** cell. A plant with many flaccid cells will show wilting.

Δ Fig. 2.20 Cells from a red onion. Left: fully turgid cells. Right: plasmolysed (flaccid) cells.

Remember boxes provide tips and guidance to help you during your course and to prepare for examination.

Questions to check your understanding.

Clearly differentiated Extended material.



EXTENDED

Much of the glucose formed by photosynthesis is converted into other substances, including **starch**. Starch molecules are large carbohydrates made of lots of glucose molecules joined together. Starch is insoluble and so can be stored in cells without affecting water movement into and out of the cells by **osmosis**. Some plants, such as potato and rice plants, store large amounts of starch in particular parts of the plant (tubers or seeds). We use these parts as sources of starch in our food.

Some glucose is converted to **sucrose** (a type of sugar formed from two glucose molecules joined together). This is still soluble, but not as reactive as glucose, so can easily be carried around the plant in solution.

The energy needed to join simple sugars to make larger carbohydrates comes from respiration.

END OF EXTENDED

QUESTIONS

1. Write the word equation for photosynthesis.
2. Explain the importance of light in photosynthesis.
3. EXTENDED a) Write the balanced symbol equation for photosynthesis.
   b) Annotate your equation to show where each of the reactants comes from, and each of the products goes to.
4. EXTENDED Explain why the transfer of energy from light to chemical energy in plant cells is essential for life on Earth.

SCIENCE LINK **CHEMISTRY – STOICHIOMETRY**

- Photosynthesis is a chemical reaction, so links to ideas about word equations and balanced symbol equations.
- Remember that the formula for each compound is fixed, so to keep in line with the law of conservation of mass we need to think about the atoms in the complete molecules when balancing an equation.
- Photosynthesis is an example of an endothermic reaction.

PHYSICS – PROPERTIES OF WAVES

- Photosynthesis requires the energy from light.
- The colours of visible light in the electromagnetic spectrum have different wavelengths. Some wavelengths are more useful in photosynthesis than others.

Investigating photosynthesis

We can use the iodine test to show that photosynthesising parts of a plant produce starch. Before carrying out this test, though, we must start by leaving the plant in a dark place for 24 hours. This will make sure that the plant uses up its stores of starch (this is known as destarching) and means that any starch identified by the test is the result of photosynthesis during the investigation.

- The production of starch after photosynthesis can be shown simply by placing a destarched plant in light for an hour. Remove one leaf and place it in boiling water for a few minutes to soften it. Then place the leaf in boiling ethanol heated in a beaker of boiling water, not over a Bunsen because ethanol fumes are flammable. This removes the chlorophyll in the leaf. When the leaf has lost its green, wash it in cold water before placing it in a dish and adding a few drops of iodine solution. The leaf should turn blue–black, indicating the presence of starch.

Δ Fig. 5.3 Preparing and testing a leaf for starch.

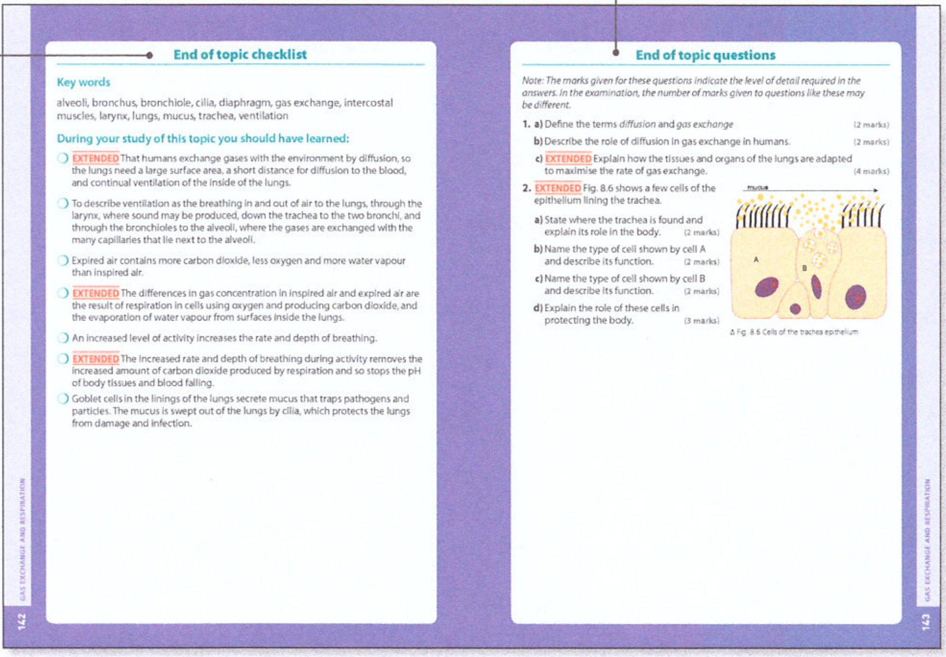
- The investigation above can be adjusted to show the need for light by covering part of the leaf before the destarched plant is brought into the light. Only the part of the leaf that received light should test positive for the presence of starch, showing that photosynthesis is linked to the production of starch.
- This investigation can also be adjusted to show the need for chlorophyll by using variegated leaves. Variegated leaves are partly green (where the cells contain chlorophyll) and partly white (where there is no chlorophyll). A variegated leaf after this investigation will show the presence of starch where there was chlorophyll but not in the parts of the leaf that had no chlorophyll.

Δ Fig. 5.4 Light was excluded from all of the lower leaf except an L-shaped window. After exposure to light, only the L shape tests positive for starch.

Science Link boxes help you to deepen your understanding of the connections between the different sciences. It is not necessary for you to learn the content of these boxes as they do not form part of the syllabus.

End of topic questions allow you to apply the knowledge and understanding you have learned in the topic to answer the questions.

A full checklist of all the information you need to cover the complete syllabus requirements for each topic.



End of topic checklist

Key words

alveoli, bronchus, bronchiole, cilia, diaphragm, gas exchange, intercostal muscles, larynx, lungs, mucus, trachea, ventilation

During your study of this topic you should have learned:

- ○ EXTENDED That humans exchange gases with the environment by diffusion, so the lungs need a large surface area, a short distance for diffusion to the blood, and continual ventilation of the inside of the lungs.
- ○ To describe ventilation as the breathing in and out of air to the lungs, through the larynx, where sound may be produced, down the trachea to the two bronchi, and through the bronchioles to the alveoli, where the gases are exchanged with the many capillaries that lie next to the alveoli.
- ○ Expired air contains more carbon dioxide, less oxygen and more water vapour than inspired air.
- ○ EXTENDED The differences in gas concentration in inspired air and expired air are the result of respiration in cells using oxygen and producing carbon dioxide, and the evaporation of water vapour from surfaces inside the lungs.
- ○ An increased level of activity increases the rate and depth of breathing.
- ○ EXTENDED The increased rate and depth of breathing during activity removes the increased amount of carbon dioxide produced by respiration and so stops the pH of body tissues and blood falling.
- ○ Goblet cells in the linings of the lungs secrete mucus that traps pathogens and particles. The mucus is swept out of the lungs by cilia, which protects the lungs from damage and infection.

142 GAS EXCHANGE AND RESPIRATION

End of topic questions

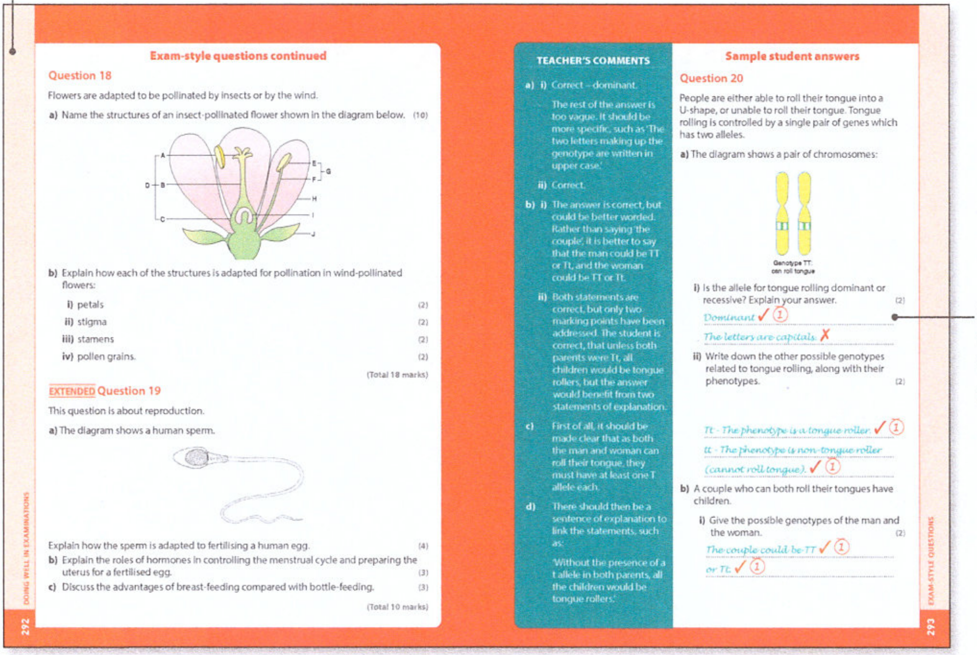
Note: The marks given for these questions indicate the level of detail required in the answers. In the examination, the number of marks given to questions like these may be different.

1. a) Define the terms *diffusion* and *gas exchange* (2 marks)
   b) Describe the role of diffusion in gas exchange in humans. (2 marks)
   c) EXTENDED Explain how the tissues and organs of the lungs are adapted to maximise the rate of gas exchange. (4 marks)
2. EXTENDED Fig. 8.6 shows a few cells of the epithelium lining the trachea.
   a) State where the trachea is found and explain its role in the body. (2 marks)
   b) Name the type of cell shown by cell A and describe its function. (2 marks)
   c) Name the type of cell shown by cell B and describe its function. (2 marks)
   d) Explain the role of these cells in protecting the body. (3 marks)

Δ Fig. 8.6 Cells of the trachea epithelium

143 GAS EXCHANGE AND RESPIRATION

Exam-style questions help you prepare for your exam in a focussed way.



Exam-style questions continued

Question 18

Flowers are adapted to be pollinated by insects or by the wind.

a) Name the structures of an insect-pollinated flower shown in the diagram below. (10)

b) Explain how each of the structures is adapted for pollination in wind-pollinated flowers:

i) petals (2)
ii) stigma (2)
iii) stamens (2)
iv) pollen grains. (2)

(Total 18 marks)

EXTENDED Question 19

This question is about reproduction.

a) The diagram shows a human sperm.

Explain how the sperm is adapted to fertilising a human egg. (4)

b) Explain the roles of hormones in controlling the menstrual cycle and preparing the uterus for a fertilised egg. (3)

c) Discuss the advantages of breast-feeding compared with bottle-feeding. (3)

(Total 10 marks)

292 DOING WELL IN EXAMINATIONS

TEACHER'S COMMENTS

a) i) Correct – dominant.

The rest of the answer is too vague. It should be more specific, such as 'The two letters making up the genotype are written in upper case.'

ii) Correct.

b) i) The answer is correct, but could be better worded. Rather than saying 'the couple', it is better to say that the man could be TT or Tt, and the woman could be TT or Tt.

ii) Both statements are correct, but only two marking points have been addressed. The student is correct, that unless both parents were Tt, all children would be tongue rollers, but the answer would benefit from two statements of explanation.

c) First of all, it should be made clear that as both the man and woman can roll their tongue, they must have at least one T allele each.

d) There should then be a sentence of explanation to link the statements, such as:

'Without the presence of a t allele in both parents, all the children would be tongue rollers.'

Sample student answers

Question 20

People are either able to roll their tongue into a U-shape, or unable to roll their tongue. Tongue rolling is controlled by a single pair of genes which has two alleles.

a) The diagram shows a pair of chromosomes:

i) Is the allele for tongue rolling dominant or recessive? Explain your answer. (2)

Dominant ✓ ①

The letters are capitals. ✗

ii) Write down the other possible genotypes related to tongue rolling, along with their phenotypes. (2)

Tt - The phenotype is a tongue roller. ✓ ①

tt - The phenotype is non-tongue roller (cannot roll tongue). ✓ ①

b) A couple who can both roll their tongues have children.

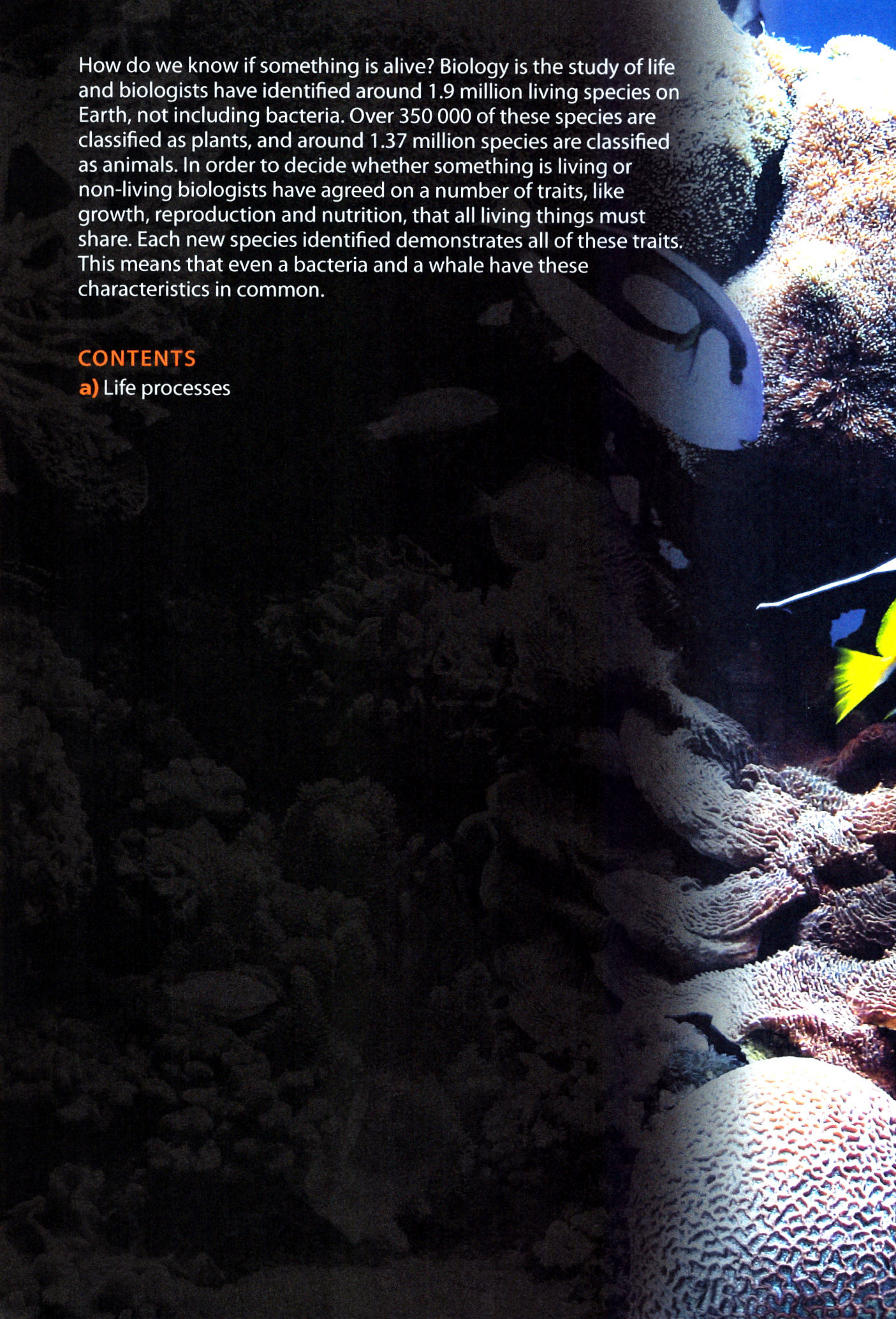
i) Give the possible genotypes of the man and the woman. (2)

The couple could be TT ✓ ①

or Tt ✓ ①

293 EXAM-STYLE QUESTIONS

Sample answers with teacher's comments to show best practice.



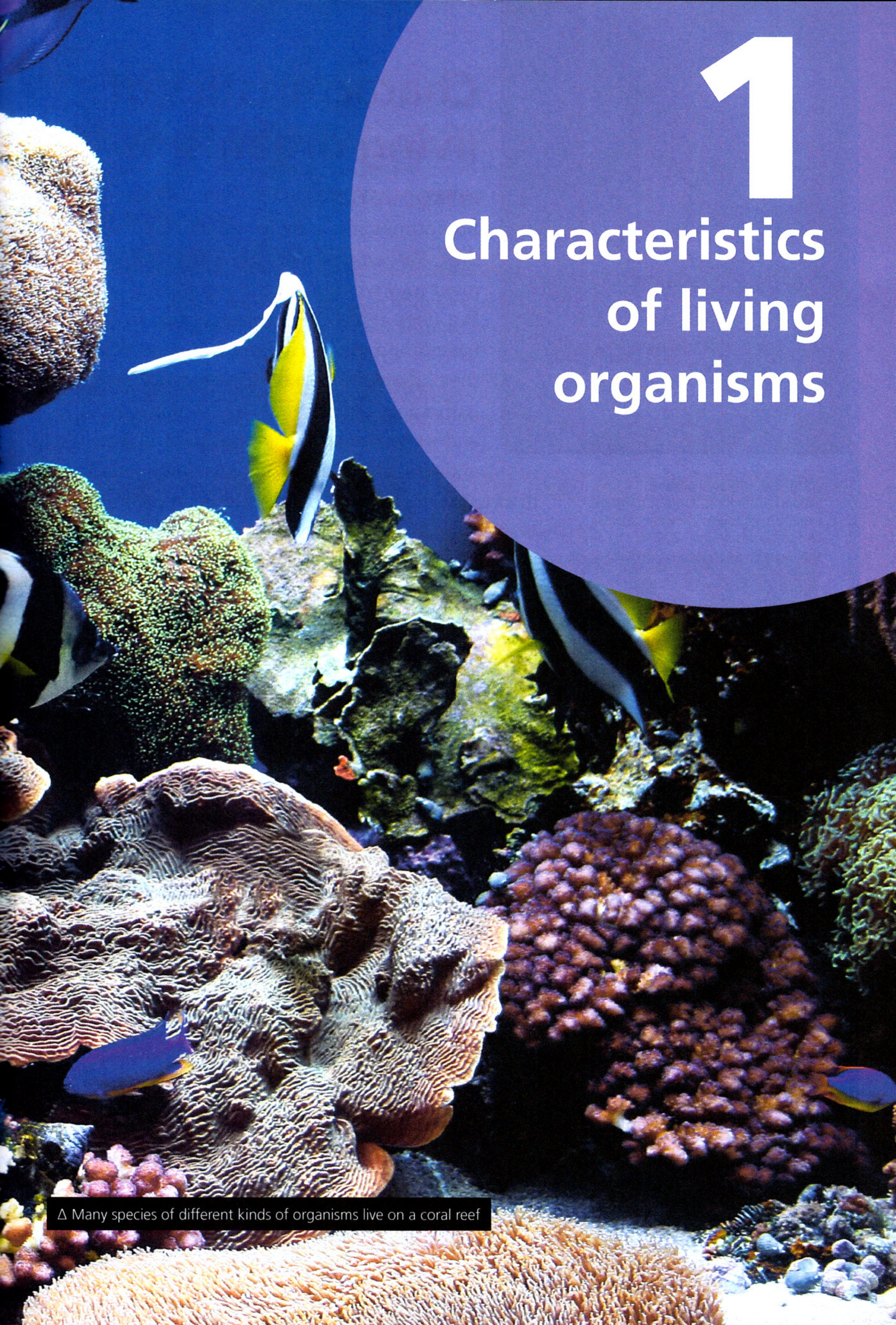
How do we know if something is alive? Biology is the study of life and biologists have identified around 1.9 million living species on Earth, not including bacteria. Over 350 000 of these species are classified as plants, and around 1.37 million species are classified as animals. In order to decide whether something is living or non-living biologists have agreed on a number of traits, like growth, reproduction and nutrition, that all living things must share. Each new species identified demonstrates all of these traits. This means that even a bacteria and a whale have these characteristics in common.

CONTENTS

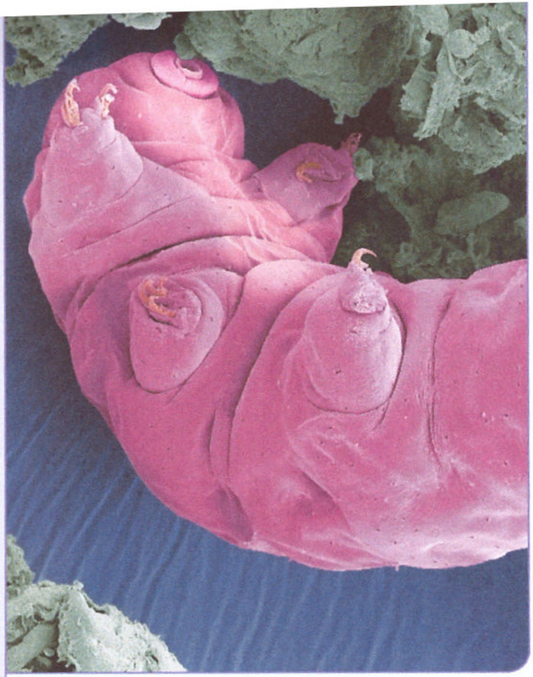
a) Life processes

1

Characteristics of living organisms



Δ Many species of different kinds of organisms live on a coral reef



Δ Fig. 1.1 Tiny tardigrades (about 1 mm long) are the toughest organisms known. They can survive temperatures below –200 °C, 10 days in the vacuum of space and over 10 years without water!

Characteristics of living organisms

INTRODUCTION

Sometimes it is easy to tell when something dies – an animal will stop moving around, a plant may wilt and all the green parts collapse. But does a tree die in winter, when its leaves have dropped off? Are animals 'dead' when they hibernate underground for months? As technology gets increasingly sophisticated, and we can create machines with 'brains' and new organisms from basic molecules, distinguishing between living and dead could get even more difficult. We need a set of 'rules' that work for most organisms, most of the time.

KNOWLEDGE CHECK

- ✓ Living organisms show a range of characteristics that distinguish them from dead or non-living material.
- ✓ The life processes are supported by the cells, tissues, organs and systems of the body.

LEARNING OBJECTIVES

- ✓ EXTENDED Define the seven characteristics of living organisms.
- ✓ Describe each of the characteristics of living organisms.
- ✓ Explain that not all living organisms show every characteristic all of the time.
- ✓ List the features shared by all living organisms.

LIFE PROCESSES

There are seven life processes that most living organisms will show at some time during their life.

- **Movement**: Animals may move their entire body so that it changes position or place.

EXTENDED

Organisms may also move parts of their body. For example, plants may move body parts in response to external stimuli such as light, while structures in the cytoplasm of all living cells move.

END OF EXTENDED

- **Respiration**: This is a series of chemical reactions inside living cells that breaks down nutrient molecules and releases energy.

EXTENDED

The energy released from respiration is used for all the chemical reactions that help to keep the body alive. Together, these reactions are known as **metabolism**.

END OF EXTENDED

- **Sensitivity**: Living organisms are able to detect (or sense) and respond to changes in the environment around them. For example, we see, hear and respond to touch.

EXTENDED

Living organisms can also detect and respond appropriately to changes inside their bodies (the internal environment).

END OF EXTENDED

- **Growth**: This is the permanent increase in size of an organism.

EXTENDED

Growth is often defined as an increase in dry mass (mass without water content) of cells or in the whole body of an organism. This is because total mass can vary, depending on how much the organism eats and drinks. Dry mass only measures the amount by which the body increases in size when nutrients are taken into the cells and used to increase their number and size.

Δ Fig. 1.2 Sunflowers respond to light by tracking the Sun across the sky during the day.

END OF EXTENDED

- **Reproduction**: This includes the processes that result in more individuals of that kind of organism, such as making gametes and the fertilisation of those gametes.
- **Excretion**: This is the removal from the body of substances that are **toxic** (poisonous) and may damage cells if they stay in the body. Organisms also excrete substances that are in **excess**, where there is more in the body than is needed.

EXTENDED

Living cells produce many products from the metabolic reactions that take place inside them. Some of these are waste products – materials that the body does not use; for example, animals cannot use the carbon dioxide produced during respiration. These waste products may be toxic, so they must be removed from the body by excretion.

END OF EXTENDED

- **Nutrition**: This is the absorption of nutrients into the body. The nutrients are the raw materials needed by the cells to release energy and to make more cells for growth, development and repair.

EXTENDED

Plant nutrition requires light, carbon dioxide, water and mineral ions, such as iron and magnesium. Animal nutrition requires organic compounds such as carbohydrates and proteins, mineral ions such as iron and sodium, and usually water.

END OF EXTENDED

All these characteristics will be described in greater detail in later topics in this book.

Δ Fig. 1.3 Growth of a child can be measured by recording the change in height over time.

QUESTIONS

1. For each of the seven characteristics, give one example for:
   a) a human
   b) an animal of your choice
   c) a plant.
2. For each of the seven characteristics, explain why they are essential to a living organism.

SCIENCE LINK

CHEMISTRY – CHEMICAL REACTIONS, PARTICLE IDEAS

- Respiration is an example of a chemical reaction.
- As with all chemical reactions, ideas about particles make it easier to understand what changes are taking place.
- Many processes in living things depend on the movement of particles (for example, the circulation of blood), so particle ideas are helpful for describing or explaining how these processes work.

PHYSICS – PROPERTIES OF WAVES

- In sensing their environment, many living things use the refraction of light through a lens to form an image.
- The vibrations of sound waves are used for hearing, different frequencies and amplitudes of sound waves producing the variety of sounds living things can sense.

An easy way to remember all seven processes is to take the first letter from each process. This spells Mrs Gren. Alternatively you may wish to make up a sentence in which each word begins with same letter as one of the processes, for example: My Revision System Gets Really Entertaining Now.

End of topic checklist

Key terms

excretion, growth, metabolism, movement, nutrition, reproduction, respiration, sensitivity

During your study of this topic you should have learned:

○ How to describe the seven characteristics of life: movement, respiration, sensitivity, growth, reproduction, excretion and nutrition.

○ **EXTENDED** How to define the seven characteristics of life.

End of topic questions

Note: The marks given for these questions indicate the level of detail required in the answers. In the examination, the number of marks given to questions like these may be different.

1. Name and describe the seven processes of life. **(7 marks)**
2. Name two life processes necessary for an organism to release energy. **(2 marks)**
3. Explain why dry mass is used to measure growth. **(2 marks)**
4. When you place a crystal of copper(II) sulfate in a saturated solution of the same compound, the crystal will increase in size. Does this mean that the crystal is alive? Explain your answer. **(2 marks)**
5. Plants cannot move about, as animals can. Does that mean animals are more alive than plants? Explain your answer. **(2 marks)**
6. During winter, an oak tree in the UK will lose its leaves and not grow. Is the tree still living during this time? Explain your answer using all the characteristics of life. **(4 marks)**

Multicellular organisms are made up of different cell types that each have a specific job to do. The human body is made up of about 200 different cell types, ranging from muscle and fat cells, to blood, skin and nerve cells.

All 'complex' cells (those that contain a nucleus) in all animals, plants and protoctists on Earth have the same basic structure. Scientists say that this is because we have all evolved from a single complex cell. This first complex cell evolved from a simple bacteria-like cell (without a nucleus) more than 1600 million years ago. This is the origin of all the millions of different species of plants, animals and protoctists that live on Earth today.

CONTENTS

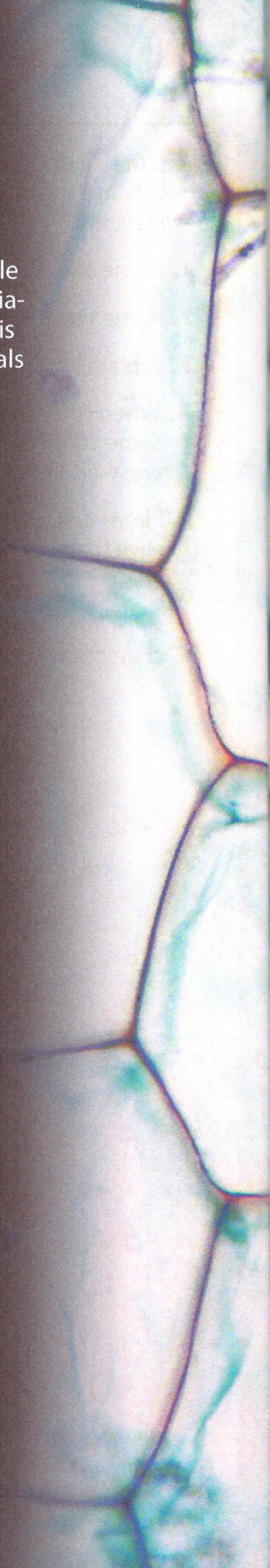
a) Plant and animal cell structure

b) Size of specimens

c) Diffusion

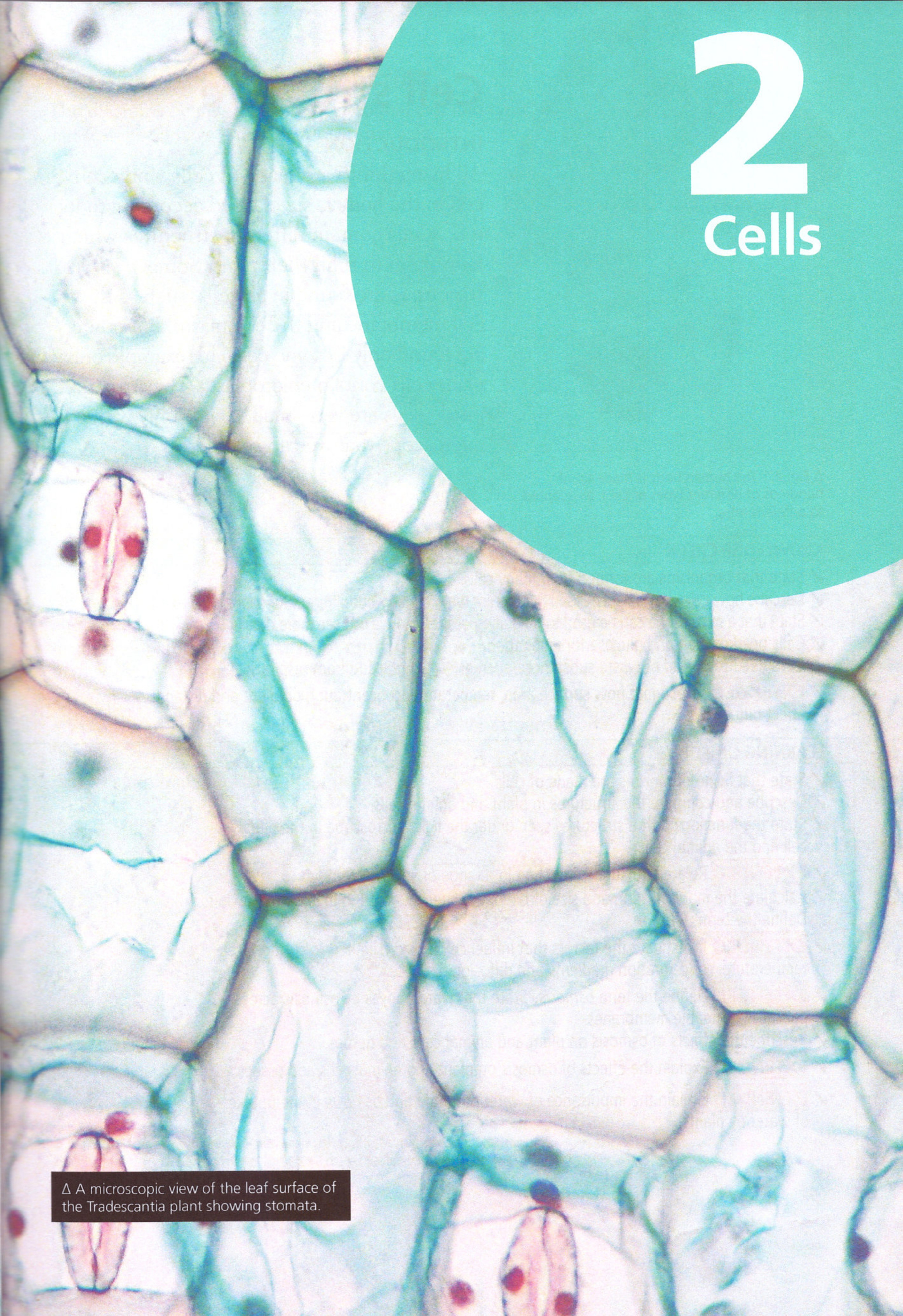
d) Osmosis

e) Water potential

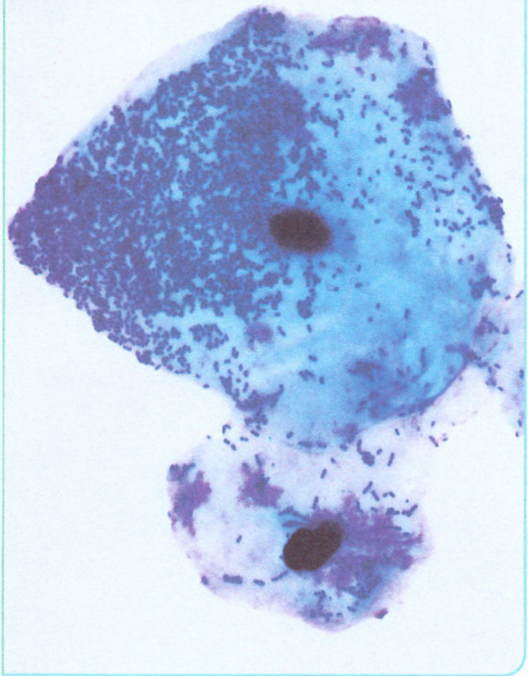


2

Cells



Δ A microscopic view of the leaf surface of the Tradescantia plant showing stomata.



Δ Fig. 2.1 The human body is made up of hundreds of different types of cells, all adapted to different roles.

Cell structure

INTRODUCTION

All living things are made of cells, and each cell in the body is specialised according to its role. Cells contain different structures which help them to fulfil their roles. Some structures are found in all cells, such as the cell membrane and the cytoplasm, but others are found only in some cells, for example only plant cells contain chloroplasts. The structures inside cells are very small, so it is only with a microscope that we can see them.

KNOWLEDGE CHECK

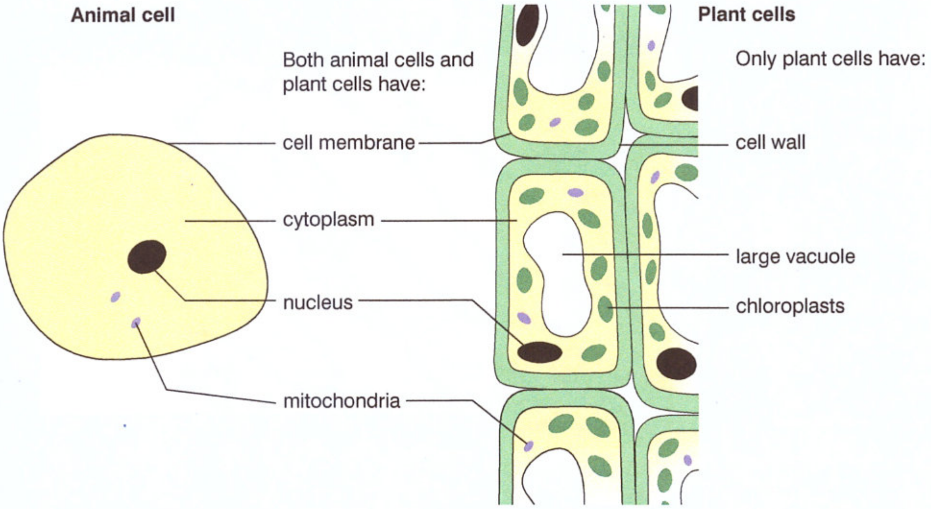
- ✓ State that organisms are formed from many cells.
- ✓ Describe how cells may be specialised in different ways to carry out different functions.
- ✓ State that a microscope can be used to magnify specimens so we can see more detail.
- ✓ Cells need oxygen and glucose for respiration.
- ✓ Cells need to get rid of waste substances, such as carbon dioxide from respiration.
- ✓ **EXTENDED** Investigate how surface area, temperature, concentration gradient and distance affect diffusion.

LEARNING OBJECTIVES

- ✓ State that living organisms are made of cells.
- ✓ Describe and compare the structures in plant and animal cells.
- ✓ State the functions of the structures seen under the light microscope in the plant cell and the animal cell.
- ✓ **EXTENDED** Relate structure to function in a range of specialised cells.
- ✓ Calculate the magnification and size of biological specimens using millimetres as units.
- ✓ Define the term *diffusion*.
- ✓ **EXTENDED** Investigate the factors that influence diffusion, limited to surface area, temperature, concentration gradients and diffusion distance.
- ✓ **EXTENDED** Define the term *osmosis*. State that water moves by osmosis across partially permeable membranes.
- ✓ Describe the effects of osmosis on plant and animal cells and tissues.
- ✓ **EXTENDED** Explain the effects of osmosis on plant and animal cells and tissues.
- ✓ **EXTENDED** Explain the importance of water potential and osmosis in the uptake of water by plants.

PLANT AND ANIMAL CELL STRUCTURE

The diagrams below show a typical animal cell and typical plant cells. These cells all have a nucleus and cytoplasm.

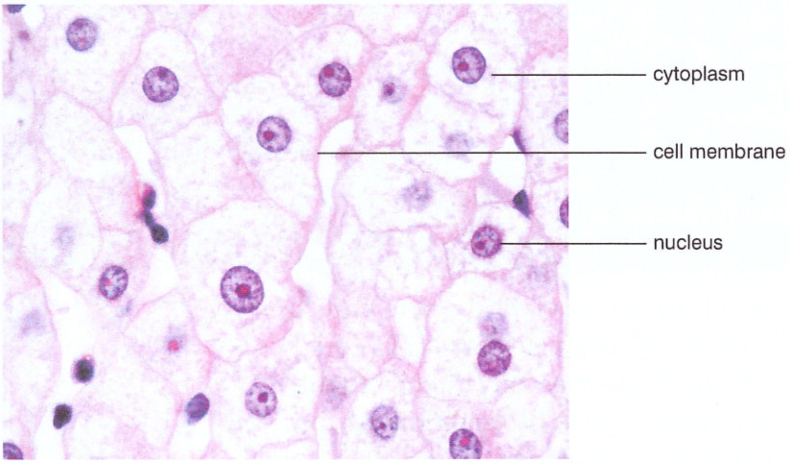

Animal cell
Plant cells
Both animal cells and plant cells have:
Only plant cells have:
cell membrane
cell wall
cytoplasm
large vacuole
nucleus
chloroplasts
mitochondria

∆ Fig. 2.2 The basic structures of an animal cell (e.g. liver cell) and plant cells (e.g. palisade mesophyll cells).

All living organisms are made of cells. Some, such as bacteria, protoctists and some fungi, are formed from a single cell; others, such as the majority of plants and animals, are **multicellular**, with a body made of many cells. All animal and plant cells have certain features in common:

- a **cell membrane** surrounds the cell
- **cytoplasm** inside the cell, in which all the other structures are found
- a large **nucleus**.

A typical animal cell is a human liver cell.

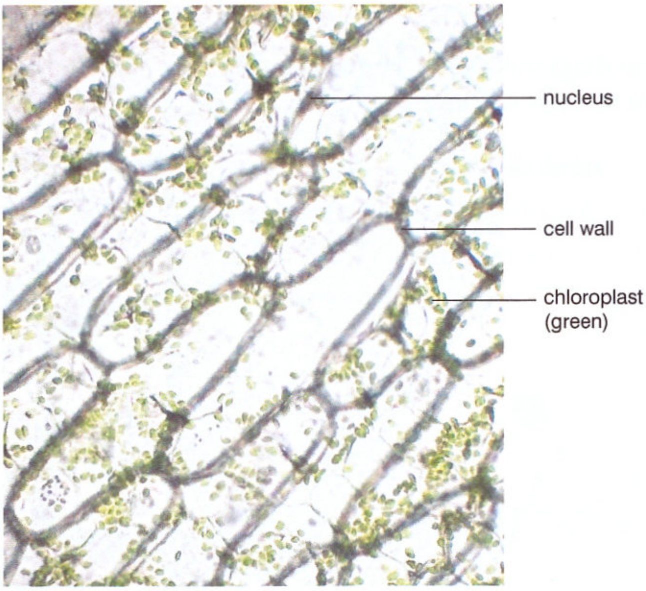

cytoplasm
cell membrane
nucleus

∆ Fig. 2.3 Structures in animal cells seen using a light microscope. Note these cells have been stained to make some structures easier to see.

Plant cells also have features that are not found in animal cells, such as:

- a **cell wall** surrounding the cell membrane
- a large central **vacuole**
- green **chloroplasts** found in some, but not all, plant cells.

A typical plant cell is a palisade cell in the upper part of a leaf.



Δ Fig. 2.4 Structures in plant cells seen using a light microscope. Note that the cell membrane and vacuole are difficult to distinguish in this image. The chloroplasts are supported by the cytoplasm.

Functions of cell structures

Each structure in a cell has a particular role.

- The cell membrane holds the cell together and controls substances entering and leaving the cell.
- The cytoplasm supports many small cell structures and is where many different chemical processes happen. It contains water, and many solutes are dissolved in it.
- The nucleus contains genetic material in the **chromosomes.** These control how a cell grows and works. The nucleus also controls cell division.
- The plant cell wall is made of cellulose, which gives the cell extra support and defines its shape.
- The plant vacuole contains cell sap. The vacuole is used for storage of some materials, and to support the shape of the cell. If there is not enough cell sap in the vacuole, the whole plant may wilt.
- Chloroplasts contain the green pigment chlorophyll, which absorbs the light energy that plants need to make food in the process known as **photosynthesis**.

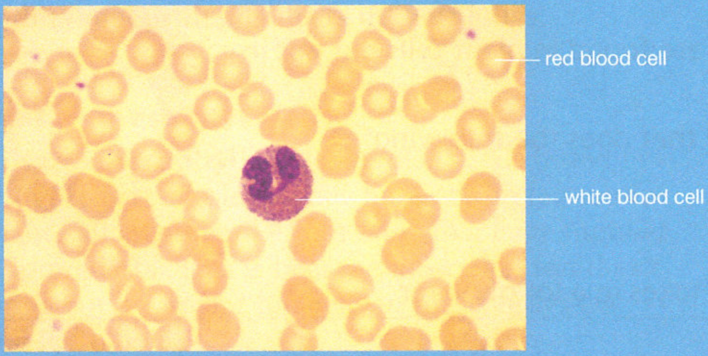
SCIENCE IN CONTEXT

ARTIFICIAL CELLS

Scientists have discovered so much about how the structures of cells are formed and work together that they are starting to create artificial cells. This has great potential for medicine, because these cells could be used, for example, to deliver drugs inside the body directly to the cells that need them. They could also be used in **biotechnology**, for example, to make fuels that could replace fossil fuels.

Developing investigative skills

The photograph shows the view of some cells seen through a light microscope.



Δ Fig. 2.5 A photograph of blood cells taken with a light microscope.

Demonstrate and describe techniques

➊ **a)** Describe how to set up a slide on a microscope so that the image is clearly focused.

b) Describe and explain what precautions should be taken when viewing a slide at high magnification.

c) Describe what precaution should be taken if using natural light to illuminate the slide, and explain why this is important.

Make observations and measurements

➋ **a)** Draw and label a diagram of the white blood cell shown in the light micrograph above.

b) If the ×10 eyepiece was used, and the ×40 objective, calculate the magnification of the image compared with the specimen on the slide. (Use the information on page 27 to help you with this.)

Analyse and interpret data

➌ Are the cells shown plant cells or animal cells? Explain your answer.

QUESTIONS

1. a) Using the photograph in Fig. 2.3, make a careful drawing of one of the cells using a sharpened pencil to make clear lines.
   b) Label your drawing to show the three key structures of animal cells.
2. List three cell structures that are found in plant cells but not in animal cells.
3. Name the part of a plant cell that does the following:
   a) carries out photosynthesis
   b) contains cell sap
   c) stops the cell swelling if it takes in a lot of water.

EXTENDED

Cell specialisation for function

Different types of cells carry out different jobs. Cells have special features that allow them to carry out their job. This is called **specialisation**. Good examples of specialised cells are:

- ciliated cells, red blood cells and sperm and egg cells in humans
- root hair cells and palisade mesophyll cells in plants.

SCIENCE IN CONTEXT

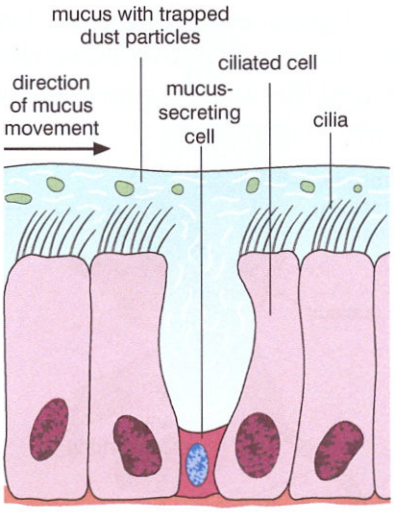
STEM CELLS

Every tissue in the human body contains a small number of undifferentiated cells. These are called **stem cells**, and their role is to divide and produce new differentiated cells within the tissue, for growth and repair. Scientists are investigating how stem cells could be given to people to mend tissue that the body cannot mend, such as the spinal cord after an accident in which it is cut. This would make it possible for a person who is paralysed following an accident to move their whole body again.

Ciliated cells

Cilia are tiny hair-like projections that cover the surfaces of certain types of cells. Cilia can move and the cell can coordinate this movement to produce waves that pass over the cell. These waves of moving cilia can move liquid in particular directions.

Ciliated epithelial cells in the lining of the respiratory tract move a liquid called mucus. Tiny particles of dust or bacteria that are trapped in the mucus are carried along in this flow and pass up the tubes. They are then emptied, along with the mucus, into the oesophagus, where they are swallowed and pass into the stomach. In this way, the ciliated epithelium keeps the lungs clean. Smoking reduces the effectiveness of these cilia, which explains why smokers often have a cough – they cannot clear away the dirty mucus that collects in their lungs.


mucus with trapped dust particles
ciliated cell
direction of mucus movement
mucus-secreting cell
cilia

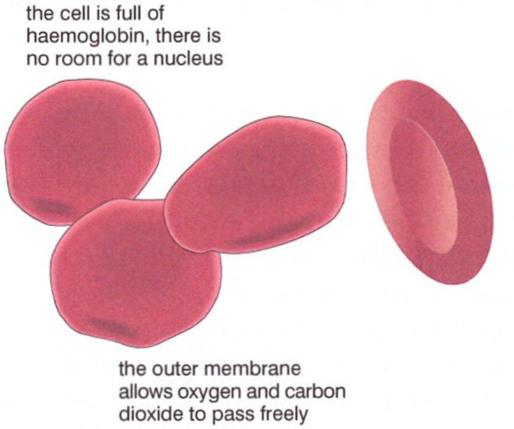
Δ Fig. 2.6 Secreting cells produce mucus that traps particles in the lungs. Cilia sweep the mucus out of the lungs and into the throat, where it is swallowed.

Palisade mesophyll cells

Palisade mesophyll cells are plant cells found in the upper part of a leaf. They have all the features of a plant cell (see Fig. 2.4) but contain a large number of chloroplasts. This is because most photosynthesis carried out by a plant happens in these cells (see more in Topic 5).

Red blood cells

Red blood cells in mammals are unusual in that they do not have a nucleus and so cannot divide. The whole of the cell is filled with a chemical called haemoglobin, which can pick up oxygen in the lungs and release it near the cells that need it deep inside the body. The shape of the cell means that the innermost part of the red blood cell is never far away from the outside, so diffusion of oxygen in and out happens very rapidly. Red blood cells are made in bone marrow and last only 120 days before they are destroyed in the spleen and liver.


the cell is full of haemoglobin, there is no room for a nucleus
the outer membrane allows oxygen and carbon dioxide to pass freely

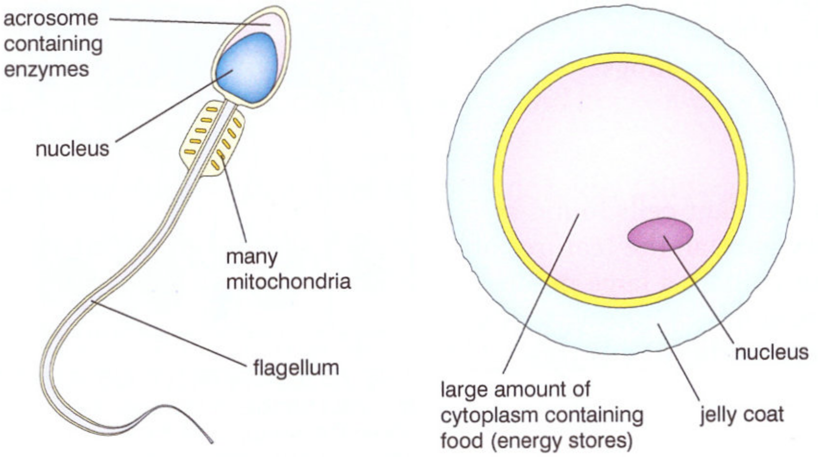
Δ Fig. 2.7 Red blood cells are specialised for carrying oxygen.

Human sex cells

The human sex cells (gametes – Topic 10) are the **sperm cell** and the **egg cell**. Sperm cells and egg cells have particular forms that are adapted to their roles in reproduction.

Sperm cells are relatively small compared with an egg cell. They have very little cytoplasm surrounding the nucleus, because they carry out few functions other than travelling to the egg cell for fertilisation. There is a small **vesicle** of enzymes, called the **acrosome**, at the front tip of the cell. The enzymes in the acrosome digest a hole in the egg cell membrane. This allows the nucleus of the sperm cell to enter the egg cell and fuse with its nucleus. The mid piece of the sperm cell contains many mitochondria. The mitochondria provide energy to move the tail (flagellum), which powers the sperm toward the egg cell.

The human egg cell is a very large cell and almost visible without a microscope. It cannot move on its own. The large amount of cytoplasm around the nucleus provides nutrients for when the cell is fertilised and starts to divide.


acrosome containing enzymes
nucleus
many mitochondria
flagellum
nucleus
large amount of cytoplasm containing food (energy stores)
jelly coat

Δ Fig. 2.8 Diagrams of a human sperm cell (left) and human egg cell (right). Note these are not drawn to scale. An egg cell is around 20 times larger than a single sperm cell.

Root hair cells

In many plants, water and minerals are absorbed from the soil by root hairs, which penetrate the spaces between soil particles. These hairs are very fine extensions of the **root hair cells** on the root surface, just behind the growing tip of a root. The elongated shape of the cells increases the surface area available for absorption of water and dissolved mineral ions. As they age, root hairs develop a waterproof layer and become non-functional. New root hairs are constantly growing as the root pushes through the soil.

Δ Fig. 2.9 The root hair cells greatly increase the surface area for absorption near the tips of roots.

QUESTIONS

1. EXTENDED Where would you find the following cells and what do they do?

   a) ciliated cells

   b) red blood cells

   c) root hair cells

2. EXTENDED Describe how the structures of sperm and egg cells are adapted to their functions in reproduction.

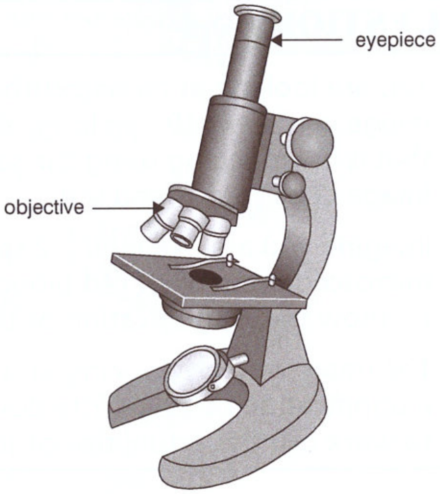
END OF EXTENDED

SIZE OF SPECIMENS

Magnification

Many of the structures that we study in biology are too small to be seen just using our eyes. We can use magnifying glasses and microscopes to examine details of plant and animal cells, and to take the pictures and draw the diagrams you see in this book. But often we want to know the actual size of the specimen we are looking at. If we know the magnification we are using to look at a specimen, then we can work out the size of a structure.

When using a microscope, the **magnification** of a specimen is calculated from the eyepiece and the objective used to view it.



∆ Fig. 2.10 A light microscope.

- The magnification of an eyepiece for a light microscope may be ×4, ×5 or ×10.
- The magnification of an objective for a light microscope may be ×5, ×10, ×20 or ×40.

The magnification of the specimen is the magnification of the eyepiece multiplied by the magnification of the objective.

WORKED EXAMPLES

1. If the microscope is set up with the ×5 eyepiece and ×20 objective, the magnification of a specimen viewed will be:

$$5 \times 20 = 100$$

We can work out the *size of a structure* from the image size seen under the microscope and the magnification used to view it.

actual size = observed size/magnification

The observed size is measured using a scale, such as a **graticule**, viewed through the microscope.

2. If the diameter of a cell observed under a microscope is 6 mm, and the magnification is ×400, the actual diameter of the cell is:

$$6/400 = 0.015 \text{ mm}.$$

SCIENCE LINK

PHYSICS – PROPERTIES OF WAVES

- Light microscopes make use of lenses and mirrors, so ideas about reflection and refraction are important.
- The magnification of a microscope is related to the refracting power of the lenses, which in turn depends on their shape and the refractive index of the glass.

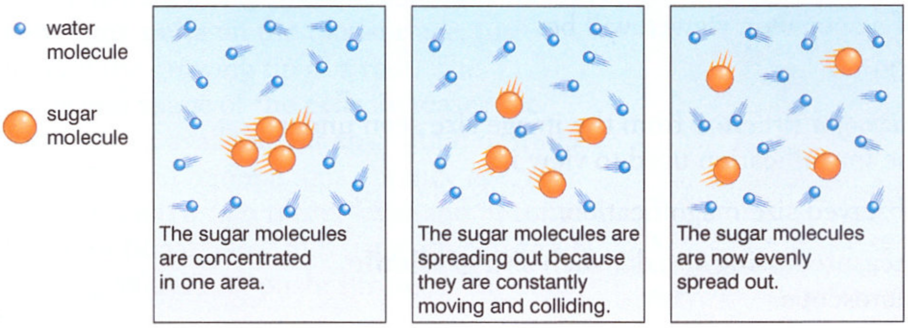
QUESTIONS

1. You are looking at an object that measures 0.5 mm and the image you see is 10 mm long. Your friend is looking at an object that is 0.1 mm long using the same magnification. What size of image does your friend see?
2. Imagine you are examining a specimen of blood under a microscope to look at red blood cells. Why might it be important to know the magnification of the lens you are using?
3. The image you are looking at is 2.5 mm long and you are using a magnification of 100. Write down the calculation you would use to work out the actual size of the object.

DIFFUSION

Substances such as water, oxygen, carbon dioxide and food are made of particles (atoms, ions and molecules).

In liquids and gases, the particles are constantly moving around. This means that they eventually spread out evenly. For example, if you dissolve sugar in a cup of water, even if you do not stir it, the sugar molecules eventually spread throughout the liquid. This is because all the molecules are moving around, colliding with and bouncing off other particles.


water molecule
sugar molecule
The sugar molecules are concentrated in one area.
The sugar molecules are spreading out because they are constantly moving and colliding.
The sugar molecules are now evenly spread out.

Δ Fig. 2.11 Diffusion of sugar molecules in a solution.

The sugar molecules have spread out from an area of high concentration, when they were added to the water, to an area of low concentration. Eventually, although all the particles are still moving, the sugar molecules are evenly spread out and there is no longer a **concentration gradient**.

Δ Fig. 2.12 Potassium permanganate(II) diffuses through a beaker of water as the solid crystal dissolves.

Only while there is **net movement** (where there are more particles moving in one direction than another) from an area of high concentration to an area of lower concentration is there **diffusion**.

Diffusion is the net movement of molecules from a region of their higher concentration to a region of their lower concentration.

Diffusion can only occur when there is a difference in concentration between two areas. Particles are said to move *down* their concentration gradient. This happens because of the random movement of particles.

Diffusion in cells

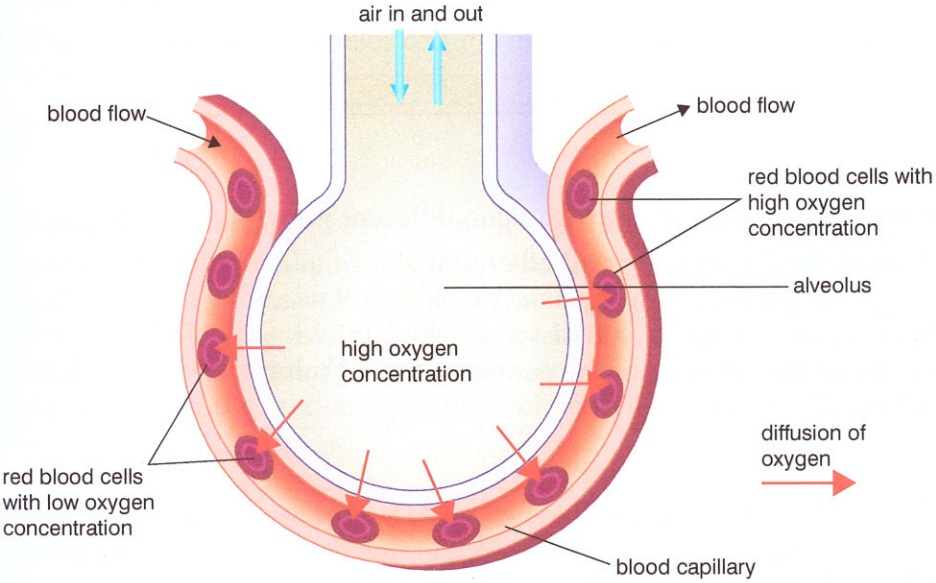
Cells are surrounded by membranes. These membranes are leaky – they let tiny particles pass through them. Large particles can't get through, so cell membranes are said to be **partially permeable**.

Movement of particles across a cell membrane may happen more in one direction than the other if there is a difference in concentration on either side of the membrane (a concentration gradient). For example, in the blood vessels in the lungs there is a *low* oxygen concentration inside the red blood cells (because they have given up their oxygen to cells in other parts of the body) and a *high* oxygen concentration in the alveoli of the lungs. Therefore, oxygen diffuses from the alveoli into the red blood cells.

Other examples of diffusion include:

- carbon dioxide entering leaf cells (see Topic 5)
- digested food substances from the small intestine entering the blood.

Diffusion allows some types of molecules across the cell membrane. It is a **passive** process, meaning it needs no input of energy from the cell.

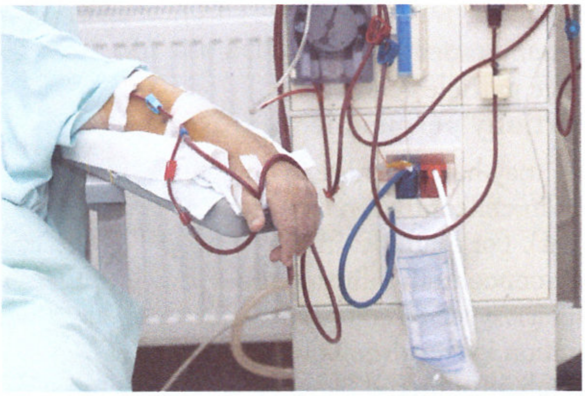

air in and out
blood flow
blood flow
red blood cells with high oxygen concentration
alveolus
high oxygen concentration
diffusion of oxygen
red blood cells with low oxygen concentration
blood capillary

Δ Fig. 2.13 In blood vessels in the lungs, oxygen diffuses down its concentration gradient from the air in the lungs into red blood cells.

SCIENCE IN CONTEXT

KIDNEY FAILURE AND HAEMODIALYSIS

The **kidneys** are organs that depend on filtration and diffusion to produce urine and keep the concentration of many substances in the blood at a fairly constant level. People who suffer from kidney failure are unable to do this, and are very quickly at risk from the build-up of waste products, such as urea, in the body as a result of cell processes. In high concentrations these waste products can damage body cells and lead to death.



Δ Fig. 2.14 A patient undergoing kidney dialysis.

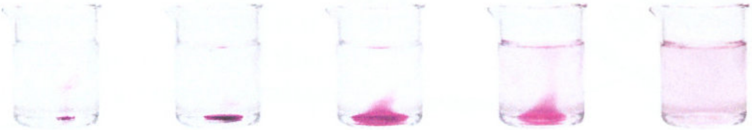
Haemodialysis is an artificial way of cleaning the blood by which substances diffuse out of the blood into dialysis fluid in a machine called a dialyser. The concentration of substances in the dialysis fluid has to be correct, so that all the waste products are removed and other substances are returned to the body at the right concentration.

EXTENDED

Investigating diffusion

Diffusion in non-living systems may be investigated in different ways.

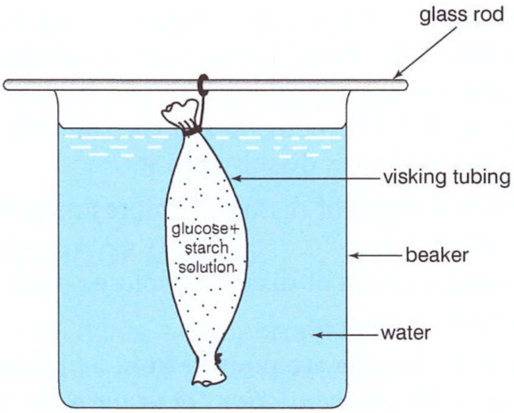
- It can be studied simply by dropping a coloured crystal of a simple soluble substance such as potassium manganate(VII) into still water, and watching what happens. As the crystal dissolves, the particles of solute diffuse throughout the water until the concentration of solute is the same throughout the water.



Δ Fig. 2.15 Left: as the crystal dissolves it forms a region of high concentration of the solute in the solution. Right: after a few hours, the solute is evenly spread in the water as a result of diffusion.

- Visking tubing is an artificial partially permeable membrane that can be used to model diffusion across cell membranes. You can create a small bag shape by knotting one end of some tubing. If you place a solution of glucose and starch into the bag, and suspend it in a beaker of water for a few hours, you can then test the water in the beaker for reducing sugar (glucose) and starch. The tests will show that glucose has diffused through the membrane, but the starch has not, because glucose molecules are small enough to pass through the holes but the starch molecules are too large.

Diffusion in cells may be investigated by looking at coloured cells, such as red onion or beetroot cells. If slices of tissue from these are left in water, after a while the colour will start to diffuse out of the cells into the water.



Δ Fig. 2.16 Visking tubing can act as a model for the cell membrane.

END OF EXTENDED

QUESTIONS

1. In your own words, define the terms *net movement* and *diffusion*.
2. Is diffusion across a cell membrane a passive or active process? Explain your answer.
3. Explain why some particles can diffuse through cell membranes but not others.

OSMOSIS

Water molecules are small enough to diffuse through partially permeable membranes, such as cell membranes. However, because water molecules are so important to cells, and may be diffusing in a different direction to other molecules, this kind of diffusion has a special name – **osmosis**. Like diffusion, osmosis is a passive process and is a result of the random movement of particles.

EXTENDED

Water molecules diffuse from a place where there is a high concentration of water molecules (such as a dilute sucrose sugar solution) to where there is a low concentration of water molecules (such as a concentrated sucrose sugar solution).

Osmosis is the diffusion (net movement) of water molecules from a region of their higher concentration to a region of their lower concentration through a partially permeable membrane.

Concentrations in solutions

Many people confuse the concentration of the solution with the concentration of the water. Remember, in osmosis it is the *water molecules* that we are considering, so you must think of the concentration of water molecules in the solution instead of the concentration of solutes dissolved in it.

- A low concentration of dissolved solutes means a high concentration of water molecules.
- A high concentration of dissolved solutes means a low concentration of water molecules.

So the water molecules are moving from a *high concentration* (*of water molecules*) to a *low concentration* (*of water molecules*), even though this is often described as water moving from a low-concentration solution to a high-concentration solution.

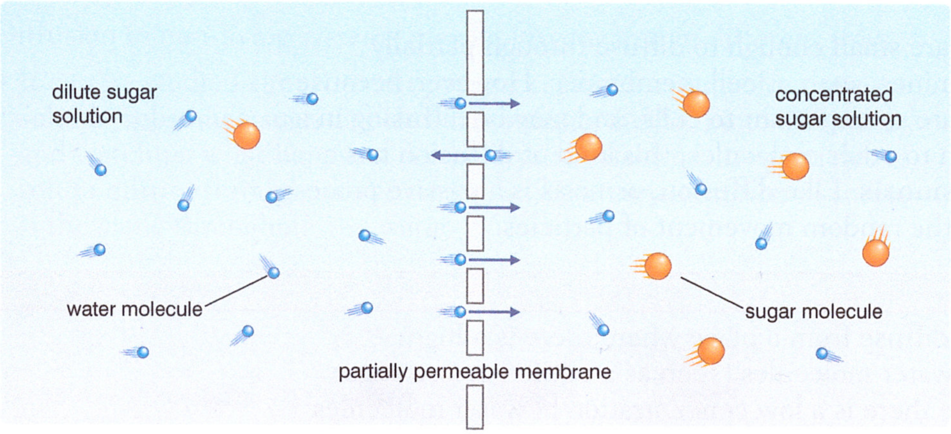
END OF EXTENDED

Osmosis in plant cells

If a cell is placed in a solution that has a higher concentration of solute (and so a lower concentration of water molecules) than the cytoplasm inside the cell, water will leave the cell by osmosis and the cytoplasm will shrink.

If a cell is placed in a solution that has a lower concentration of solute (and so a higher concentration of water molecules) than the cytoplasm inside the cell, osmosis will result in water entering the cell.

Plant cells are surrounded by cell walls that are completely permeable. This means water and solute molecules pass easily through them.



Δ Fig. 2.17 Water molecules diffuse from an area of higher concentration (of water molecules) into an area of lower concentration (of water molecules). This kind of diffusion is known as osmosis.

In a solution of high concentration of solute (low concentration of water), water will leave a plant cell by osmosis. This can be seen in plant cells as the cytoplasm shrinks inside the cell. However, the whole cell doesn't shrink, because the plant cell wall controls the structure of the cell. The plant as a whole will show wilting.

In a solution of low concentration of solute (high concentration of water), water will enter the plant cell by osmosis. However, the plant cell does not eventually burst. The strong cell wall provides strength when the cytoplasm is full of water, preventing the cell from expanding any further and bursting.

SCIENCE LINK

CHEMISTRY – PARTICLE NATURE OF MATTER

- Particle ideas, particularly the properties of fluids, are important in describing and explaining how substances are able to move into and out of cells.
- The movement of water molecules is particularly important and particle ideas help explain how they can move through a partially permeable membrane while other molecules do not.

Developing investigative skills

Strips of dandelion stem about 5 cm long and 3 mm wide were placed in sodium chloride solutions of different concentrations. After 10 minutes, the strips looked as shown in the diagram. (Note that the outer layer of a dandelion stalk is 'waterproofed' with a waxy layer to protect it from water loss to the environment.)

Extension

How could you adapt this experiment to show that other factors influence diffusion?

Design experiments which could be used to investigate the influence of:

a) surface area
b) temperature
c) concentration gradient
d) diffusion difference.

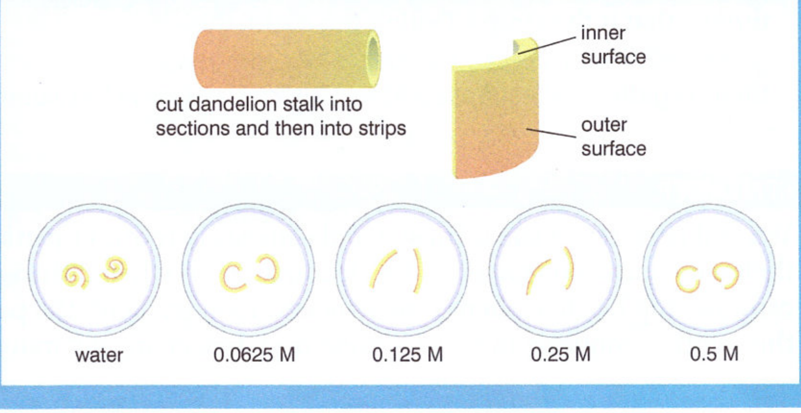


Fig. 2.18 Investigating osmosis. ▷

Devise and plan investigations

❶ Write a plan for an experiment to carry out this investigation. Your plan should include:

a) instructions on how to prepare the stem samples

b) instructions on how to keep the stem samples until the experiment starts.

Make observations and measurements

❷ Using the diagram, describe the results of this investigation.

Analyse and interpret data

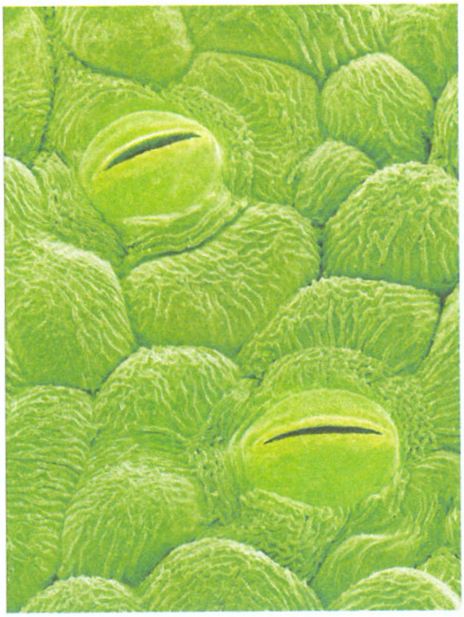
❸ Explain as fully as you can the results of this investigation.

❹ Use the results to suggest the normal concentration of cell cytoplasm. Explain your answer.

SCIENCE IN CONTEXT

STOMATA

Stomata (single: stoma) are the holes in the surface of a leaf (usually the undersurface) that allow air to move into and out of the leaf. This provides the oxygen for respiring cells and carbon dioxide for photosynthesising cells, and allows water vapour that has evaporated from cell surfaces inside the leaf to diffuse out into the atmosphere.



Δ Fig. 2.19 Each stoma is surrounded by two guard cells.

Each stoma is surrounded by two guard cells. These control the opening and closing of the stoma. Usually stomata are open during the day, and closed at night. The stoma opens and closes as the guard cells change shape. During the day, the guard cells gain water from surrounding cells as a result of osmosis. This makes the cells turgid and, because the inner edge of the guard cell does not stretch, the cells curve and create a space between them – that is the stoma. During the night, the guard cells lose water by osmosis. The cells lose their turgidity and collapse a little, closing the stoma between them.

REMEMBER

You will need to explain diffusion and osmosis in terms of particles and their concentration gradients. Be clear that, even when diffusion and osmosis stop because there is no concentration gradient, the particles in the solution continue to move – there is no longer any *net* movement.

QUESTIONS

1. EXTENDED In your own words, define the term *osmosis*.
2. Explain how osmosis is
   a) similar to diffusion
   b) different from diffusion.

EXTENDED

WATER POTENTIAL

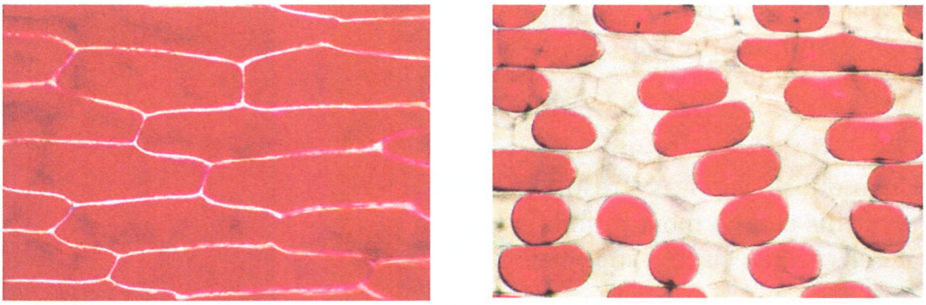
The ability of a cell to draw water into itself is called its **water potential**. Pure water has a water potential of zero. As solutes are added to the water, its water potential falls – it becomes more negative. So, a concentrated sugar solution has a lower water potential (more negative) than pure water.

When two regions of different water potential are separated by a partially permeable membrane, water moves from the region of higher water potential to lower water potential. Water molecules move *down* the **water potential gradient**.

Turgid and flaccid cells

A **turgid** plant cell is one that is full of water. The pressure of the water in the cytoplasm in a turgid cell against the cell wall is called **turgor pressure**. This pressure prevents any more water entering the cell by osmosis, even if it is in a solution that has a higher water concentration than the water concentration of the cytoplasm.

A plant cell that is dehydrated is said to be **plasmolysed**. This happens when the cytoplasm shrinks and the cell membrane pulls away from the cell wall leaving a gap between the wall and the membrane. Such a cell may also be called a **flaccid** cell. A plant with many flaccid cells will show wilting.



Δ Fig. 2.20 Cells from a red onion. Left: fully turgid cells. Right: plasmolysed (flaccid) cells.

Osmosis and plant uptake of water

Plant roots are surrounded by soil water, and the cytoplasm inside root hair cells has a lower concentration of water molecules than the soil water. So water molecules will cross the cell membrane of root hair cells and enter the plant as a result of osmosis.

The water molecules that enter the root hair cells increase the cells' concentration of water molecules, so that it is higher than the concentration of water molecules in surrounding cells. So water molecules cross the cell membranes of the root hair cells into the other cells. This raises their concentration of water molecules, and makes it higher than the concentration in cells even further into the root tissue, so water molecules cross those cell membranes. Osmosis continues from the surface root hair cells, deeper and deeper into the root tissue until the water molecules reach the xylem vessels. Once they have entered the xylem vessels, the water molecules are transported away from the root toward the leaves. Transpiration from the leaves (see Topic 7) helps to draw the water up the xylem tubes from the roots, so maintaining the concentration gradient between the root cells and xylem vessels.

REMEMBER

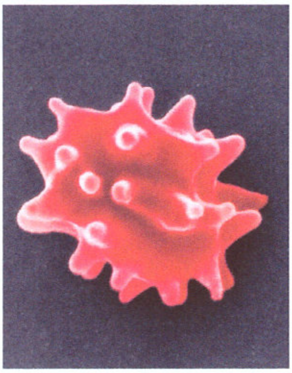
Look for applications of diffusion and osmosis in the processes that you learn about in the rest of the course, and make sure you refer to them appropriately in exam answers. For example, the fact that osmosis causes a change in shape of cells is important in the opening and closing of stomata in plants.

We can explain the movement of water molecules into and through the root of a plant in terms of water potential gradient, because the soil water has the highest water potential and the cells nearest the xylem vessels have the lowest water potential. So water molecules move into the root hair cell, and across the cells of the root, down the water potential gradient. The water potential gradient is maintained as the xylem vessels remove water molecules from the root due to transpiration from the leaves.

The effect of osmosis on animal cells

Animal cells also gain and lose water as a result of osmosis. However, the effects of this can be more dramatic than in plant cells because animal cells do not have a supporting cell wall.

If you place an animal cell (such as a red blood cell) into a solution of lower water potential, it will lose water by osmosis and become **crenated**, like the cell shown in the photograph in Fig. 2.21.



Δ Fig. 2.21 A red blood cell that has been placed in a salty solution loses water and shrinks.

If you place an animal cell into a solution of higher water potential, it will gain water by osmosis. Even when it is full of water, it will continue to take in water if the water potential is higher outside the cell than inside. The cell membrane is not strong, so if it is stretched too far it will burst.

END OF EXTENDED

SCIENCE IN CONTEXT

OVERHYDRATION

It is possible (although not easy) to die as a result of drinking too much water. If you drink a large volume of water very quickly, the water moves into the blood – and from there into cells – by osmosis.

The cells in the brain are particularly at risk because the brain has a limited space within the skull. If the brain cells swell quickly as a result of osmosis, the increased brain volume can cut off the blood supply, and brain cells start to die. Fortunately, we have an effective mechanism for getting rid of extra water from the body in urine, so overhydration is rare.

QUESTIONS

1. **EXTENDED** Explain the meaning of the following terms:

  a) *flaccid*

  b) *turgid*

  c) *plasmolysis*

  d) *turgor pressure.*

2. **EXTENDED** Describe the uptake of water from the soil by plant roots in terms of water potential gradient.

3. **EXTENDED** Draw a labelled diagram to show what happens to the water molecules when a red blood cell is placed in a solution that has a higher concentration of solute than the cytoplasm of the cell. Your labels should include the terms *water potential* and *osmosis.*

End of topic checklist

Key terms

cell membrane, cell wall, chloroplast, ciliated cell, cytoplasm, egg cell, magnification, multicellular, nucleus, photosynthesis, red blood cell, root hair cell, specialisation, sperm cell, vacuole, concentration gradient, diffusion, flaccid, net movement, osmosis, partially permeable, passive, plasmolysed, turgid, water potential gradient

During your study of this topic you should have learned:

- ○ How to describe structures inside cells including the nucleus, cytoplasm, cell membrane, cell wall, chloroplast and vacuole.
- ○ That the cytoplasm, cell membrane, cell wall, chloroplast and vacuole have specific roles in cells.
- ○ That plant and animal cells have some structures in common, but plants also have cell walls, chloroplasts and large central vacuoles that animal cells do not have.
- ○ The magnification of a specimen seen under a microscope is the magnification of the eyepiece multiplied by the magnification of the objective used.
- ○ The size of a structure seen under a microscope is the measured size divided by the magnification.
- ○ How to calculate the magnification and size of biological specimens.
- ○ To define diffusion as the net movement of particles from a region of their higher concentration to a region of their lower concentration, and as a passive process.
- ○ That water diffuses through partially permeable membranes by osmosis.
- ○ **EXTENDED** To define osmosis as the net movement of water molecules across a partially permeable membrane from their higher concentration (a dilute solution) to their lower concentration (a more concentrated solution), and is a passive process.
- ○ How to investigate and describe osmosis in plant tissues.
- ○ **EXTENDED** To state that diffusion results from the random movement of particles in gases and liquids.
- ○ **EXTENDED** To investigate the factors that affect diffusion.
- ○ Plant and animal cells lose water when placed in solutions of lower water concentration, and gain water in solutions of higher water concentration.
- ○ **EXTENDED** That animal cells will burst if they take in too much water because they do not have a strong cell wall.

End of topic questions

Note: The marks given for these questions indicate the level of detail required in the answers. In the examination, the number of marks given to questions like these may be different.

1. Describe the role of the following cell structures:

a) nucleus **b)** cell membrane **c)** cytoplasm. **(3 marks)**

2. Draw up a table to compare the structures found in plant and animal cells. **(12 marks)**

3. Here are some examples of statements written by students. Each statement contains an error. Identify the error and rewrite the statement so that it is correct.

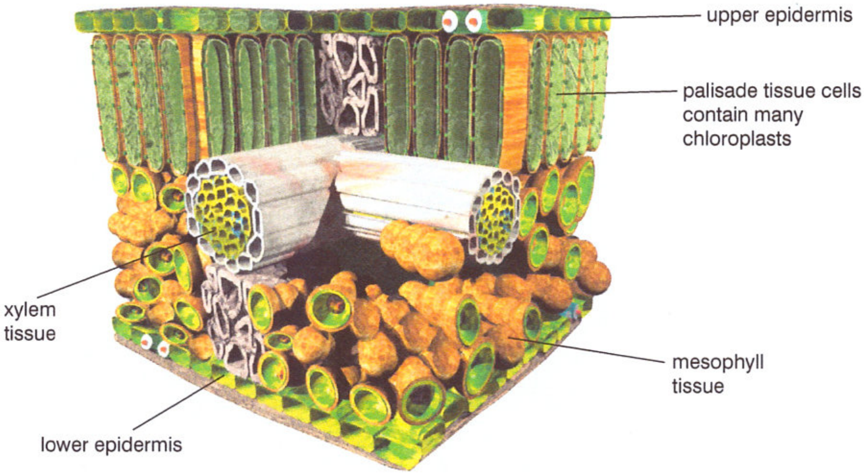
a) Animal cells are surrounded by a cell wall that controls what enters and leaves the cell. **(1 mark)**

b) All plant cells contain chloroplasts. **(1 mark)**

c) Both animal cells and plant cells contain a large central vacuole in the middle of the cell. **(1 mark)**

4. Red blood cells are unusual because they contain no nucleus. When they are damaged, they have to be replaced with new cells from the bone marrow. Explain how this is different from other cells. **(2 marks)**

5. The diagram shows a part of a leaf, which is a plant organ. The diagram is labelled to show some of the tissues. Research and describe the functions of the tissues in this organ. **(4 marks)**



Δ Fig. 2.22 Section through part of a leaf.

End of topic questions continued

6. An old-fashioned way of killing slugs in the garden is to sprinkle salt on them. This kills the slugs by drying them out. Explain why this works. **(2 marks)**

7. Copy and complete the table to compare diffusion and osmosis.

	Diffusion	**Osmosis**
Which molecule moves?		
Needs a partially permeable membrane?		
Requires a concentration gradient?		

(6 marks)

8. Which of the following are examples of diffusion, osmosis or neither?

a) Carbon dioxide entering a leaf when it is photosynthesising. **(1 mark)**

b) Food entering your stomach when you swallow. **(1 mark)**

c) A dried-out piece of celery swelling up when placed in a bowl of water. **(1 mark)**

9. Explain why a large animal, such as a human, needs special adaptations to organs that exchange materials with the environment (such as the lungs, small intestine and kidney), but a single-celled organism does not. **(4 marks)**

There are around 90 000 different proteins in the human body, and thousands more in other organisms. What is unique about proteins is that each one may be a different shape. The different shapes make it possible for proteins to carry out different roles in the body.

All these many thousands of proteins are made up of chains of smaller molecules, called amino acids, which join together in long chains. All proteins are made up from different combinations of just 20 amino acids. It is the order of these amino acids in the chain, and the way that the chain folds up into its 3D shape, that gives each protein its unique function.

CONTENTS

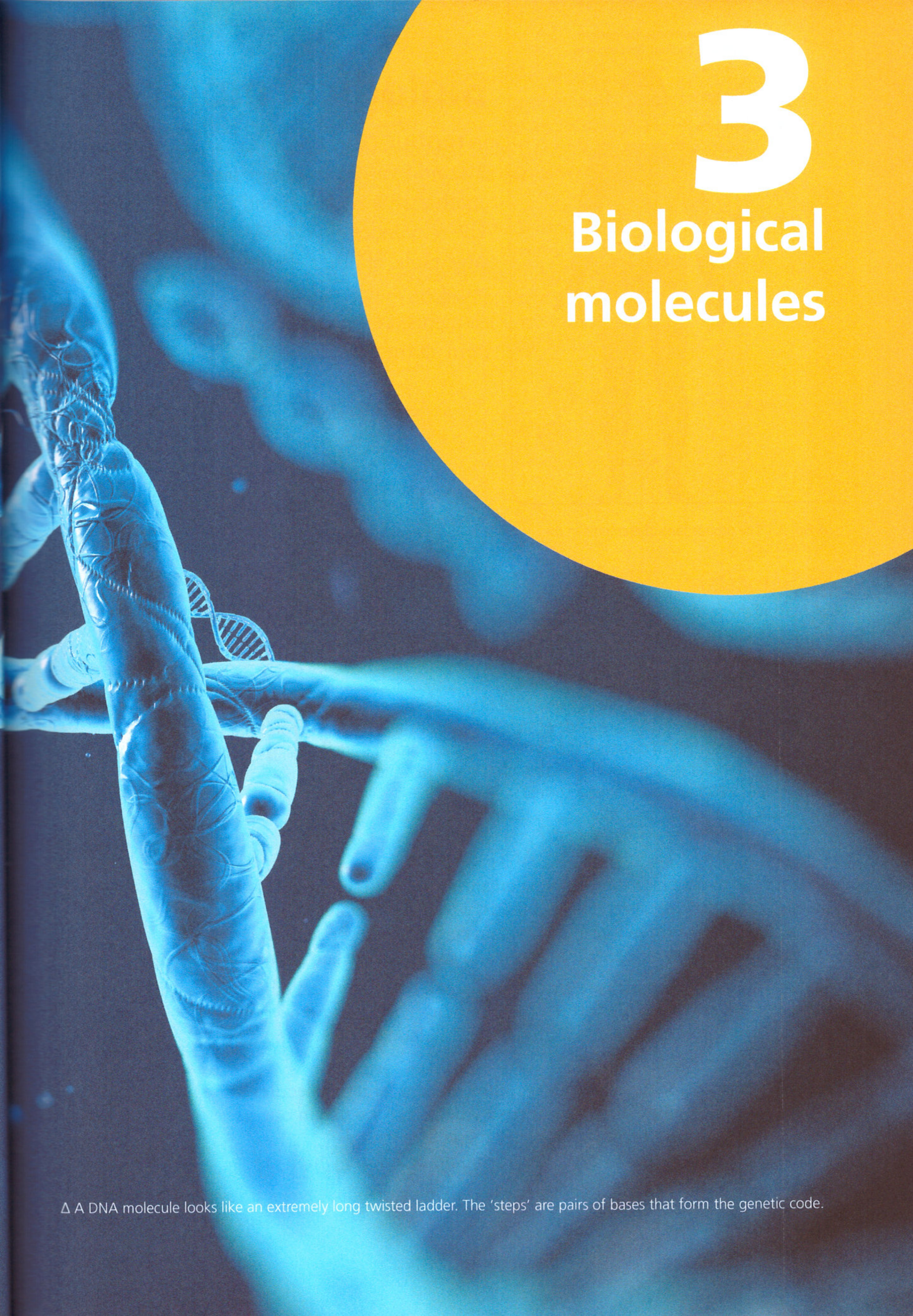
a) Carbohydrates, proteins and lipids

b) Water

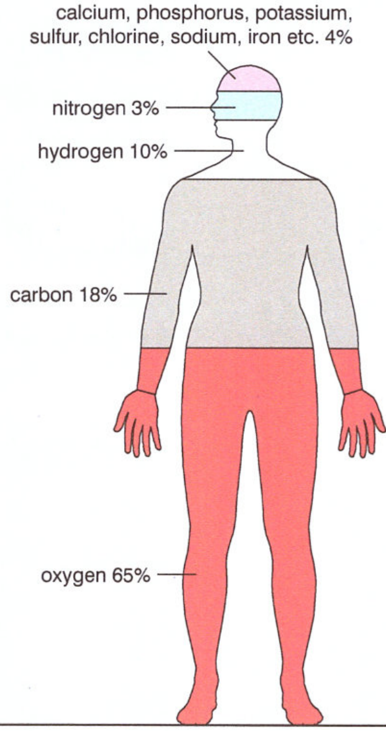
c) Tests for food molecules

3

Biological molecules



Δ A DNA molecule looks like an extremely long twisted ladder. The ‘steps’ are pairs of bases that form the genetic code.


calcium, phosphorus, potassium, sulfur, chlorine, sodium, iron etc. 4%
nitrogen 3%
hydrogen 10%
carbon 18%
oxygen 65%

Δ Fig. 3.1 The proportions of elements in the human body.

Biological molecules

INTRODUCTION

Around 65% of your body mass is oxygen, another 18% is carbon and 10% is hydrogen. The remainder of your mass is made up of a large range of other elements, including nitrogen, sulfur, calcium and iron. These elements are combined in different ways to form all the compounds in your body.

KNOWLEDGE CHECK

✓ Most of the foods that we eat can be grouped into carbohydrates, proteins and fats.
✓ Carbohydrates, proteins and fats are formed from smaller molecules.

LEARNING OBJECTIVES

✓ List the chemical elements that make up carbohydrates, fats and proteins.
✓ State that large molecules are made of smaller molecules, and be able to name the basic units from which carbohydrates, fats and oils, and proteins are made.
✓ Describe tests for starch, reducing sugars, protein and fats and oils.
✓ State that water is important as a solvent.

CARBOHYDRATES, PROTEINS AND LIPIDS

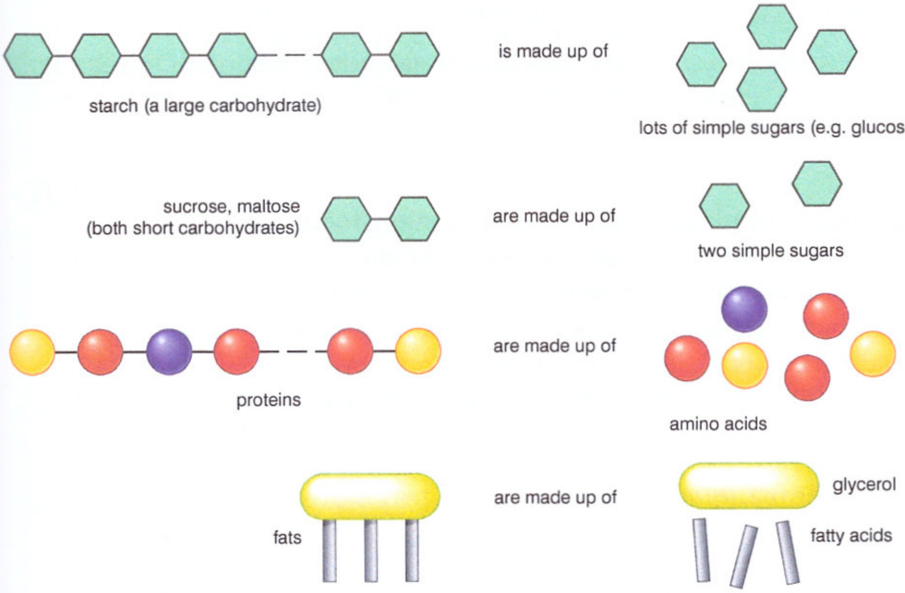
Most of the molecules found in living organisms fall into three main groups: carbohydrates, proteins, and lipids, which are commonly called fats and oils. All of these molecules contain carbon, hydrogen and oxygen. In addition, all proteins contain nitrogen and some also contain sulfur.

Carbohydrate molecules are made up of small basic units called **simple sugars**. These are formed from carbon, hydrogen and oxygen atoms, sometimes arranged in a ring-shaped molecule. One example of a simple sugar is glucose.

Simple sugar molecules can link together to form larger molecules. They can join in pairs, such as **sucrose** (the 'sugar' we use in our food). They can also form much larger molecules called polysaccharides, such as starch, glycogen and cellulose, which are long chains of glucose molecules.

Protein molecules are made up of long chains of **amino acids** linked together. There are 20 different kinds of amino acids in plant and animal cells, and they can join in any order, in long chains, to make all the different proteins within the plant or animal body. Examples include the structural proteins in muscle, as well as enzymes that help to control cell reactions.

A **lipid** is what we commonly call a fat or oil. At room temperature **fats** are solid and **oils** are liquid, but they have a similar structure. Both fats and oils are made from basic units called **fatty acids** and **glycerol**. There are three fatty acids in each lipid, and the fatty acids vary in different lipids. Lipids are important in forming cell membranes and many other molecules in the body, such as fats in storage cells.


starch (a large carbohydrate)
is made up of
lots of simple sugars (e.g. glucose)
sucrose, maltose
(both short carbohydrates)
are made up of
two simple sugars
proteins
are made up of
amino acids
fats
are made up of
glycerol
fatty acids

Δ Fig. 3.2 Large biological molecules are formed from small sub units.

QUESTIONS

1. What are the basic units of:
   a) lipids
   b) carbohydrates
   c) proteins?
2. Using the diagram of food molecules in Fig. 3.2, give two differences between the structure of a protein and a carbohydrate.

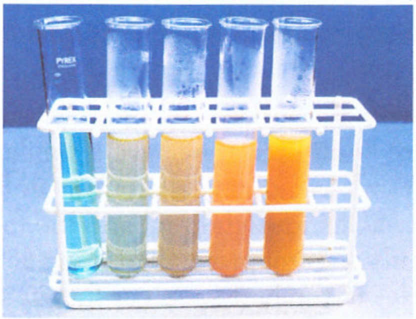
WATER

Water is essential for living organisms as it is the main part of the cytoplasm of the cell and of the plasma of the blood. Water has properties that makes it a good solvent, so many substances like glucose and salt can dissolve in it.

TESTS FOR FOOD MOLECULES

We can use simple tests to indicate whether or not a food contains particular food molecules, such as starch, glucose, proteins or lipids.

Δ Fig. 3.3 The blue–black colour shows there is starch in the biscuit.



Δ Fig. 3.4 Benedict's reagent with a range of concentrations of reducing sugars (no sugar in the tube on the left, getting more concentrated toward the right.)

Test for starch

Starch is the storage molecule of plants, and is found in many foods that are made from plant tissue. When iodine/potassium iodide solution is mixed with a solution of food containing starch, or dropped onto food containing starch, it changes from brown to dark blue. This happens when even small amounts of starch are present and can be used as a simple test for the presence of starch. The colour change is easiest to see if the test is examined against a white background, such as on a white spotting tile.

Test for glucose

Glucose is a 'reducing sugar' that is important in respiration and photosynthesis. So it is commonly found in plant and animal tissues, and therefore in our food. Its presence can be detected using **Benedict's reagent**. The pale blue Benedict's solution is added to a prepared sample that contains glucose and heated to 95 °C. If it changes colour or forms a precipitate, this indicates the presence of reducing sugars. A green colour means there is only a small amount of glucose in the solution. A medium amount of glucose produces a yellow colour. A significant amount of glucose produces a precipitate that is an orange–red colour.

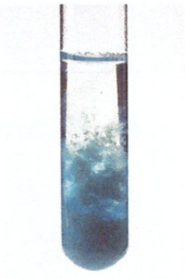
REMEMBER

The test using Benedict's reagent will produce an orange–red precipitate for any reducing sugar, such as the simple sugars fructose and galactose, and the disaccharides (made from two basic units: *di-* means 'two' or 'double') lactose and maltose. So, it is not exclusively a test for glucose. But as glucose is the most common sugar, this is the test usually used for it.

Test for protein

The **biuret test** is used to check for the presence of protein. A small sample of the food under test is placed in a test tube.

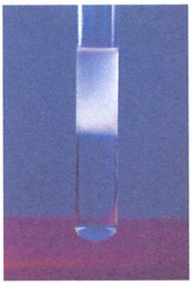
An equal volume of biuret solution is carefully poured down the side of the tube. If the sample contains protein, a blue ring forms at the surface. If the sample is then shaken, the blue ring disappears and the solution turns a light purple.



Δ Fig. 3.5 A positive biuret test for protein.

Test for fat

This test depends on the fact that fats and oils do not dissolve in water, but do dissolve in ethanol. The test sample is mixed with ethanol. If fat is present, it will be dissolved in the ethanol to form a cloudy solution. The liquid formed is poured into a test tube of water, leaving behind any solid that has not dissolved. If there is any fat dissolved in the ethanol, it will form a cloudy white precipitate when mixed with the water.



Δ Fig. 3.6 Fats have dissolved in the top layer of ethanol, making it appear cloudy.

QUESTIONS

1. Describe what you would see if you tested a sample of the following with (i) Benedict's solution and (ii) iodine solution:
   - a) glucose syrup
   - b) a cake made with wheat flour, table sugar (sucrose), fat and eggs.

   Explain your answers.
2. Explain how you would test the seed from a walnut tree to see if it contained stores of:
   - a) fat
   - b) protein.

SCIENCE LINK

CHEMISTRY – ATOMS, ELEMENTS AND COMPOUNDS

- Biological molecules can be very complicated, but they are still made from the same simple atoms as all other materials.
- Ideas about conservation of mass mean that only the atoms available at the start of any change can be present at the end (and they must *all* be there!).
- Carbohydrates, composed of the elements carbon, hydrogen and oxygen, are particularly important in this topic.
- Some of the larger molecules (such as starch) are made by joining smaller, simpler molecules together (glucose in the case of starch).
- Chemical tests, such as adding iodine, are used to identify a range of different substances.

End of topic checklist

Key words

amino acid, Benedict's reagent, biuret test, carbohydrate, fat, fatty acid, glycerol, lipid, oil, protein, simple sugar, starch, water

During your study of this topic you should have learned:

○ That carbohydrates, proteins, fats and oils all contain the elements carbon, hydrogen and oxygen.

○ That proteins also contain the element nitrogen and some may contain sulfur.

○ That large carbohydrates, such as starch and glycogen, are made up of smaller carbohydrates (reducing sugars), such as glucose.

○ Proteins are made of smaller molecules called amino acids.

○ To state that water is an essential solvent for living organisms.

○ To state that fats and oils are made of smaller molecules called fatty acids and glycerol.

○ To describe the use of the iodine test to identify the presence of starch.

○ To describe the use of Benedict's reagent to test for the presence of simple reducing sugars, such as glucose.

○ To describe the use of the biuret test to identify the presence of proteins.

○ To describe the use of the ethanol emulsion to identify the presence of fats and oils.

End of topic questions

Note: The marks given for these questions indicate the level of detail required in the answers. In the examination, the number of marks given to questions like these may be different.

1. **a)** Explain why carbon, hydrogen and oxygen are the most common elements found in the human body. **(1 mark)**

   b) Why does the body need other elements, in addition to those mentioned in part **(a)**? **(1 mark)**

2. A sample of bread was ground up. Some of the breadcrumbs were tested with Benedict's reagent and some with iodine solution. The rest of the crumbs were mixed with Substance A. After 20 minutes, some of the mixture was tested with Benedict's reagent and some with iodine solution. The results of the tests are shown in the table.

	Test with Benedict's solution	**Test with iodine solution**
Before adding Substance A	no precipitate	change to blue-black colour
After 20 min with Substance A	orange-red precipitate	no colour change

   a) Describe what the results show. **(2 marks)**

   b) What was Substance A? Explain your answer. **(4 marks)**

Many useful enzymes come from bacteria and other microorganisms, and these organisms are harnessed both in industry and in the home, for uses as wide ranging as washing detergents, to baking leavened bread. Yeast is a single-celled organism that produces enzymes that break down the sugars in flour, and in the process tiny bubbles of carbon dioxide gas are released, which cause the bread to rise.

The first enzyme used commercially in washing products was introduced in the 1960s. It was a protease that broke down protein-based stains such as blood, and it was extracted from a bacterium. Since then, a much wider range of enzymes has been added to washing products, to digest fats, starches and other molecules.

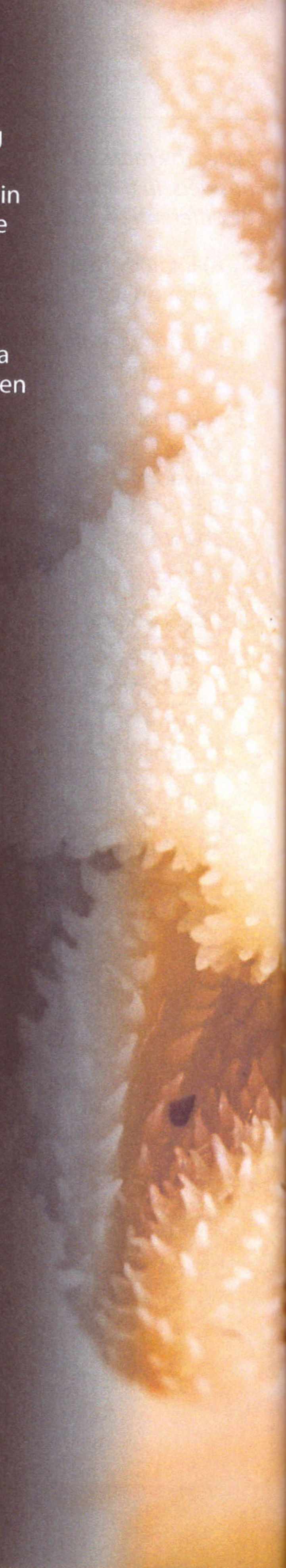
CONTENTS

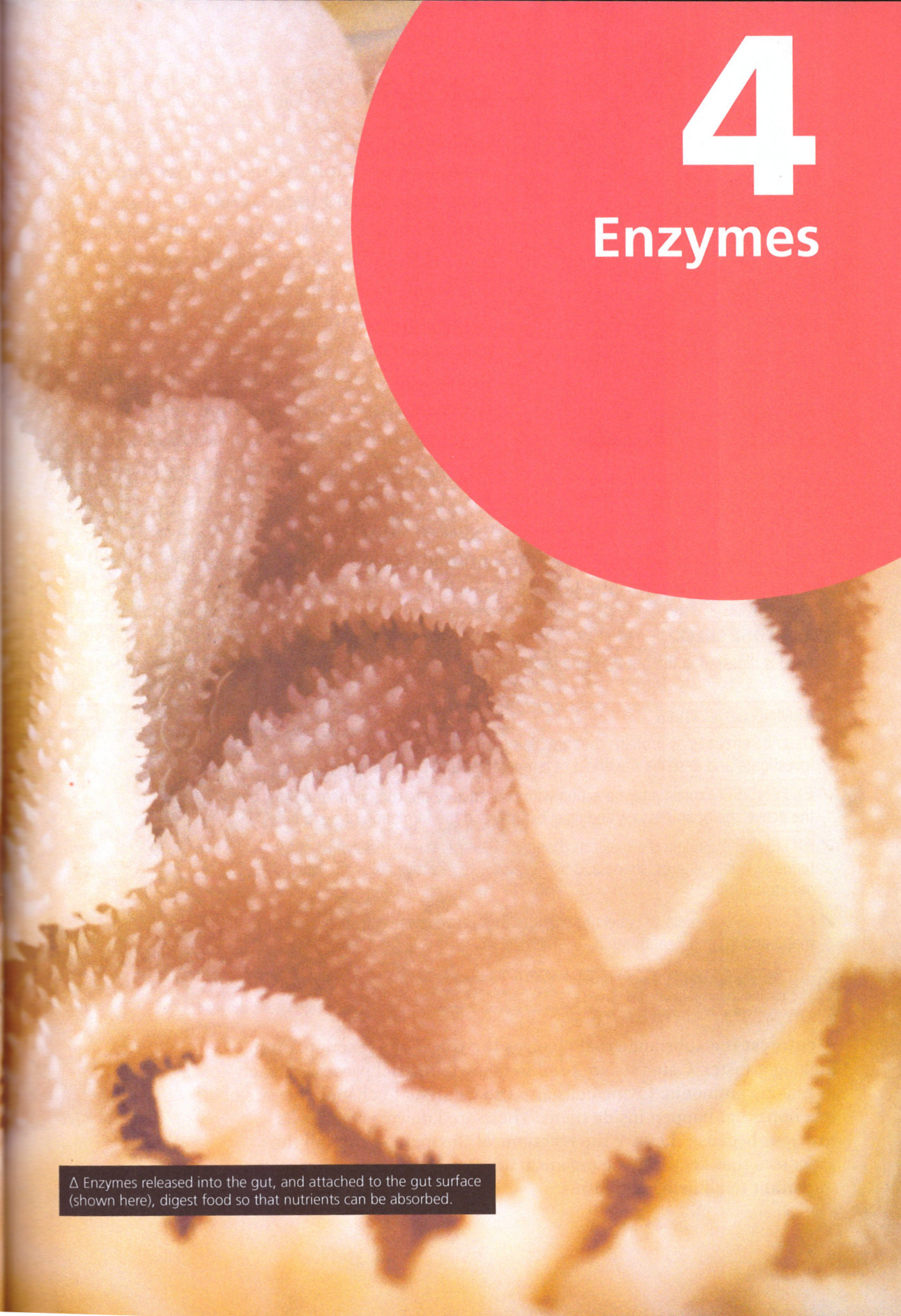
a) Enzymes as catalysts

b) Enzyme action

c) Enzymes and temperature

d) Enzymes and pH





4

Enzymes

Δ Enzymes released into the gut, and attached to the gut surface (shown here), digest food so that nutrients can be absorbed.

Δ Fig. 4.1 Enzymes in the mouth, stomach and small intestine will break down this food into much smaller molecules.

Enzymes

INTRODUCTION

Many of our staple foods, such as rice, potato, pasta and bread, contain large quantities of starch. Take a mouthful of one of these, without anything else, and you won't taste a lot to start with. But continue chewing on it for a few minutes, to mix it with saliva and reduce it to a slush, and you will find it starts to taste sweeter. This is because there are enzymes in saliva that start to break down the starch into smaller sugar molecules that taste sweet. Enzymes are essential in digestion, to break down the large molecules in our food into molecules that are small enough for diffusion through the cells of the gut wall and into our bodies.

KNOWLEDGE CHECK

✓ Food is digested in the gut into smaller molecules.

LEARNING OBJECTIVES

✓ Describe enzymes as proteins that are biological catalysts.
✓ Investigate and describe the effect of temperature and pH on enzyme activity.
✓ **EXTENDED** Explain enzyme action with reference to the complementary shape of the active site of an enzyme and its substrate, and the formation of a product.
✓ **EXTENDED** Explain the effect of changes in temperature on enzyme activity, in terms of kinetic energy, shape and fit, frequency of effective collisions and denaturation.
✓ **EXTENDED** Explain the effect of changes in pH on enzyme activity in terms of shape and fit, and denaturation.

ENZYMES AS CATALYSTS

A **catalyst** is a substance that changes the speed of a reaction, often making it faster. Catalysts are used in many industrial processes, such as making ammonia. Living cells also use catalysts to change the rate of reactions that happen inside them. These are known as *metabolic reactions* because they are the reactions of the metabolism (all the processes that keep a living organism alive). This makes enzymes very important to all living organisms.

Catalysts that control metabolic reactions are **enzymes** and, because they work in living cells, they are called **biological catalysts**. Enzymes are proteins. They help cells carry out all the life processes quickly. Without them, most metabolic reactions would happen too slowly for life to carry on.

Some enzymes help two or more small molecules join together, such as when the polysaccharides starch and glycogen are built from glucose. Other enzymes help large molecules break down into smaller ones, such as when proteins are broken down into separate amino acids.

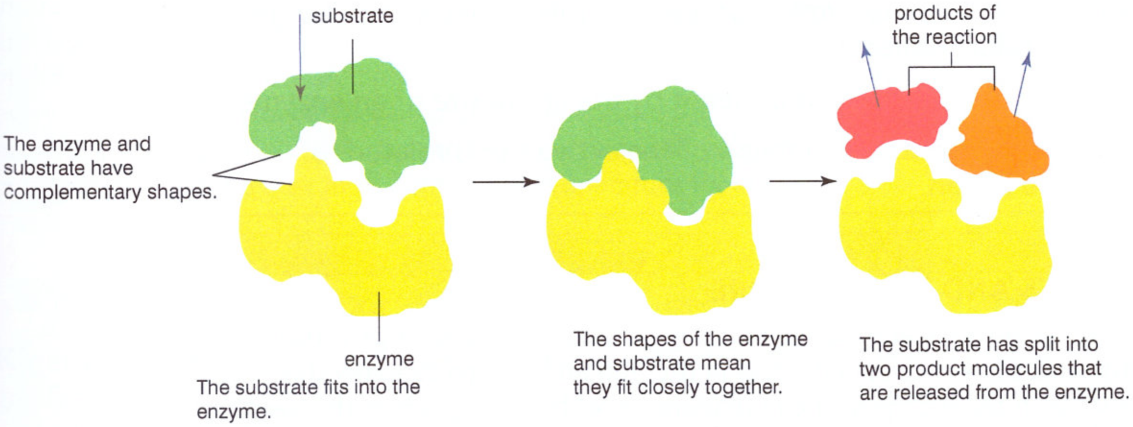
A molecule that an enzyme joins with at the start of a reaction is called a **substrate**, and the molecule that is formed by the end of the reaction is called a **product**. So, during a reaction, substrate molecules are changed to product molecules.

QUESTIONS

1. Explain what is meant by *biological catalyst*.
2. Define the terms *substrate* and *product*.

ENZYME ACTION

Enzymes are proteins and, like all proteins, they have a three-dimensional (3D) shape produced by the way the molecule folds up. Enzymes have a space in the molecule with a particular 3D shape. This space matches the shape of the substrate molecule. We say the shapes are **complementary**, because the substrate fits neatly into the space in the enzyme, like fitting two jigsaw pieces together.


substrate
The enzyme and substrate have complementary shapes.
enzyme
The substrate fits into the enzyme.
The shapes of the enzyme and substrate mean they fit closely together.
products of the reaction
The substrate has split into two product molecules that are released from the enzyme.

Δ Fig. 4.2 In this reaction, the enzyme helps a substrate molecule split into two product molecules.

EXTENDED

The space in the enzyme shape into which the substrate fits is called the enzyme's **active site**. The substrate fits tightly into the active site, forming an enzyme–substrate complex. This makes it easier for the bonds inside the substrate to be rearranged to form the products. Once the products are formed, they no longer fit the active site, so they are released, leaving the active site free and the enzyme unchanged. This means the enzyme molecule is able to bind with another substrate molecule.

Explaining enzyme action

Enzymes are **specific**, which means that each enzyme only works with one substrate or a group of similar-shaped substrates. For example:

- amylase is a type of carbohydrase enzyme produced in the mouth, which starts the digestion of starch in food into simple sugars
- proteases are digestive enzymes that break down proteins into smaller units
- lipases are digestive enzymes that break down lipids in foods.

The complementary shapes of the enzyme and substrate help to explain enzyme action, because only a substrate with the correct shape can fit into the active site and so be affected by the enzyme.

END OF EXTENDED

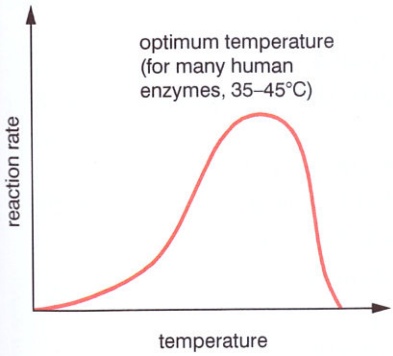
QUESTIONS

1. Describe how an enzyme causes a substrate molecule to change into product molecules.
2. EXTENDED Explain what is meant by the *active site* of an enzyme.
3. EXTENDED Explain how shape of the active site is related to enzyme action.

ENZYMES AND TEMPERATURE

Enzymes work best at a particular temperature, called their **optimum temperature**. For many enzymes in the human body, particularly those that work in the organs in the core (centre) of the body, such as the heart, liver, kidneys and lungs, the optimum temperature is around 37 °C.

At lower temperatures, enzymes in the human body work more slowly. At temperatures that are much higher than the optimum, the structure of an enzyme will be changed so that it will not work. This is a permanent change and, when it happens, the enzyme is said to be **denatured**.



Δ Fig. 4.3 Many enzymes work best at an optimum temperature.

REMEMBER

Remember the relationship between enzyme activity, temperature and pH, particularly when discussing homeostasis (Topic 9), as this helps to explain why maintaining particular conditions in the body is so important for health.

Investigating the effect of temperature on enzymes

The effect of temperature on an enzyme can be tested by measuring the rate of action of the enzyme at different temperatures. One method is shown in the Developing investigative skills box. Alternatively, you could use the following method to investigate the optimum temperature of amylase.

Starch is broken down to glucose by the enzyme amylase. Starch reacts with iodine solution by turning it blue–black. Glucose does not react with iodine solution, leaving it bright orange. If you mix starch solution with amylase solution and place different tubes of the mixture in water baths of different temperature and take a sample for testing with iodine solution every minute or so, you can see at which temperature the amylase works fastest. The sample that is the first to stop reacting with iodine solution comes from the tube kept at the optimum temperature for amylase.

EXTENDED

The effect of temperature

Kinetic energy is the energy of moving particles. Particles that have a greater kinetic energy move more or move faster. The kinetic energy of molecules that are free to move will cause them to bump into surrounding molecules. The kinetic energy of atoms held within larger molecules by bonds will cause them to vibrate.

An enzyme molecule and substrate molecule can only form an enzyme–substrate complex when they bump into each other with sufficient energy, and the substrate fits into the active site.

- At a low temperature the enzyme and substrate molecules move slowly, so they may take a long time to bump into each other with enough force to join and start the reaction.

- As the temperature increases, the molecules gain more energy and move faster, so the chance of them bumping into each other and joining together increases. The rate of reaction increases up to the optimum temperature.
- Beyond the optimum temperature, the atoms in the enzyme molecule are vibrating so much that they start to change the shape of the active site. This means the substrate doesn't fit as well, so the chances of an enzyme–substrate molecule forming decreases. The rate of reaction decreases.
- If the temperature increases too much, the bonds between atoms in the enzyme molecule start to break, changing the shape of the active site permanently and denaturing the enzyme.

END OF EXTENDED

Developing investigative skills

Developed black-and-white negative film consists of a celluloid backing covered with a layer of gelatin. Where the film has been exposed, the gelatin layer contains tiny particles of silver, which make that area black. Gelatin is a protein and is easily digested by proteases.

Strips of exposed film were soaked in protease solution at different temperatures. When the gelatin had been digested, the silver grains fell away from the celluloid backing, leaving transparent film. The table shows the results.

Tube	Temperature in °C	Time to clear
1	10	6 min 34 s
2	20	3 min 15 s
3	30	2 min 43 s
4	40	3 min 55 s
5	50	8 min 33 s

Devise and plan investigations

❶ Describe how you would set up this investigation to get results like those shown in the table.

Analyse and interpret data

❷ Draw a graph using the data in the table.

❸ Describe the shape of the graph.

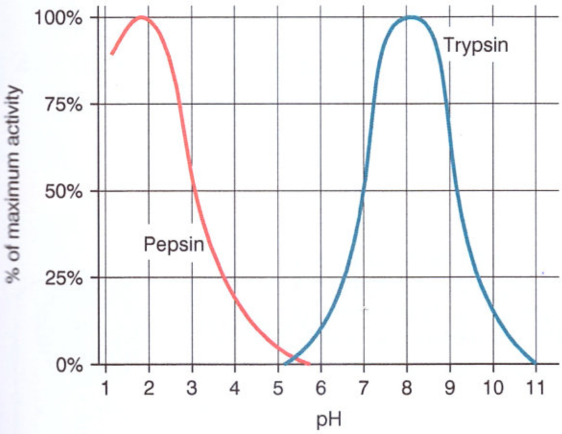
❹ Explain the shape of the graph.

Evaluate data and methods

❺ How could you modify this experiment to get a more accurate estimate of the optimum temperature for this enzyme?

ENZYMES AND pH

Enzymes also often work best at a particular pH, called their **optimum pH**. Extremes of (very high or very low) pH can slow down the rate of action of the enzyme and even denature it.

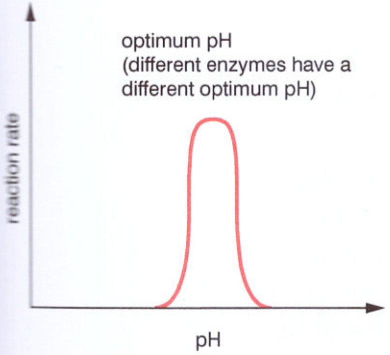


Δ Fig. 4.4 Pepsin (an enzyme found in the stomach) and trypsin (an enzyme released into the small intestine) have different optimum pHs.

Different enzymes have different optimum pHs, depending on where they are normally found in the body. Pepsin digests proteins in the stomach, which is a highly acidic environment. Trypsin digests proteins in the small intestine, where conditions are more alkaline.

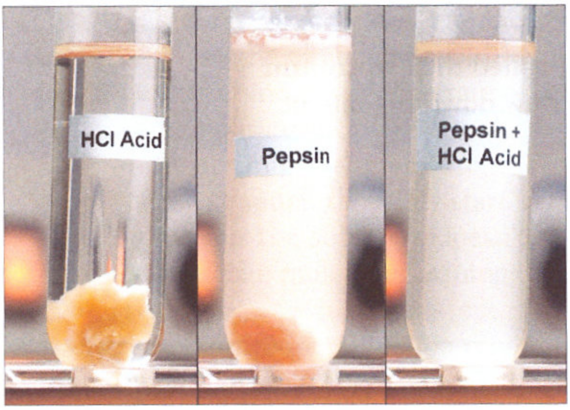
Investigating the effect of pH on enzymes

You can investigate the effect of pH on amylase enzyme using a similar method to the one described for temperature (page 58).



Δ Fig. 4.5 Many enzymes work best at an optimum temperature.

Set up one tube for each pH to be investigated and add buffer solution, which will keep the contents at a particular pH. Add starch solution to each tube, and then amylase solution. Take a sample from each tube every minute or so and test for starch using iodine solution. The sample that is the first to stop turning iodine solution blue–black comes from the tube where digestion of starch to glucose was fastest, and therefore from the tube kept at the optimum pH for that enzyme.



Δ Fig. 4.6 The tubes show the results of an experiment on the digestion of meat. Pepsin is a protease enzyme that is released in the stomach where it starts the digestion of proteins in food. Acid is also secreted into the stomach contents, reducing the pH and providing the optimum pH for pepsin. The left tube shows that acid has no effect on the meat. The middle tube shows that pepsin on its own digests the meat slowly. Only when the pepsin is mixed with acid can the enzyme work quickly to digest the protein.

QUESTIONS

1. Describe the effect of temperature on the rate of an enzyme-controlled reaction.
2. Compare the optimum pHs for pepsin and trypsin, shown in the graph in Fig. 4.4, and explain the differences.

EXTENDED

The effect of pH

Proteins are made of amino acids, joined together in a chain. The amino acids then interact with nearby amino acids, which causes the chain to fold up into the 3D shape of the enzyme.

Some of the interactions between amino acids in the enzyme molecule depend on the pH of the surrounding solvent. So, the shape of the enzyme will depend on the surrounding pH. If the pH changes too much from the optimum pH, the shape of the enzyme, and particularly its active site, will change. So, the substrate will not fit as well and the rate of reaction will decrease.

QUESTIONS

1. Explain the effect of temperature on enzyme activity:
   a) at temperatures below the optimum
   b) at temperatures above the optimum.
2. Explain the effect of pH on pepsin (see graph in Fig. 4.4) in terms of the active site of the enzyme.

END OF EXTENDED

SCIENCE LINK

CHEMISTRY – CHEMICAL REACTIONS

- Catalysts are present in a range of chemical reactions that happen in a biological context (remember that they help the chemical reaction to happen without being 'used up').
- As with any chemical reactions, those involving enzymes are affected by temperature, so ideas about how the motion and energy of particles vary at different temperatures are important.
- Enzymes are affected by the acidity of their environment, which links to ideas about pH, acids, bases and alkalis.

End of topic checklist

Key terms

active site, biological catalyst, catalyst, denature, enzyme, optimum pH, optimum temperature, product, specific, substrate

During your study of this topic you should have learned:

○ How to define enzymes as proteins that are biological catalysts, which control the rate of metabolic reactions.

○ How to investigate the optimum temperature of enzymes at which the rate of reaction occurs most rapidly; the rate is slower at lower temperatures, and also at higher temperatures when the enzyme molecule starts to denature.

○ That enzymes may have an optimum pH at which the rate of reaction happens most rapidly.

○ How to describe the importance of enzymes in all living organisms.

○ **EXTENDED** How to explain the active site as the space in the enzyme into which the substrate fits neatly during a reaction.

○ **EXTENDED** Explain that a temperature lower than the optimum causes a slower rate of an enzyme-controlled reaction because the molecules move around more slowly and so don't come into contact with each other as often.

○ **EXTENDED** How to explain that a temperature higher than the optimum causes a slower rate of an enzyme-controlled reaction because the vibration of atoms in the enzyme slightly changes the shape of the active site so that the substrate does not fit as easily into it.

○ **EXTENDED** How to explain that a very high temperature denatures the enzyme as interactions between amino acids break and change the shape of the active site completely.

○ **EXTENDED** How to explain that pH affects the interactions between amino acids in the enzyme molecule and so the ability of the substrate to fit into the active site.

○ **EXTENDED** How to describe enzyme action with reference to the active site, substrate and product.

End of topic questions

Note: The marks given for these questions indicate the level of detail required in the answers. In the examination, the number of marks given to questions like these may be different.

1. There are around 75 000 different enzymes in the human body. Explain why we need so many. **(2 marks)**

2. Describe how you would investigate the optimum temperature for a particular enzyme. **(4 marks)**

3. Sketch a graph to show the effect of temperature on the rate of reaction for an enzyme from humans. Label the value of the optimum temperature on your graph. **(2 marks)**

4. The body has many mechanisms for keeping internal conditions within limits. One of the internal conditions that is controlled is the concentration of carbon dioxide in the blood. Carbon dioxide gas is acidic and highly soluble.

a) Which process in cells produces carbon dioxide? **(1 mark)**

b) How is this gas removed from the body? **(1 mark)**

c) What would you expect to happen to the amount of carbon dioxide in the body during exercise? Explain your answer. **(2 marks)**

d) What effect would exercise have on conditions inside cells if the carbon dioxide was not removed? **(1 mark)**

e) What problem would this cause for enzymes and the cell processes that they control? **(2 marks)**

5. **EXTENDED** Explain fully the shape of the graph you drew for Question 3. **(5 marks)**

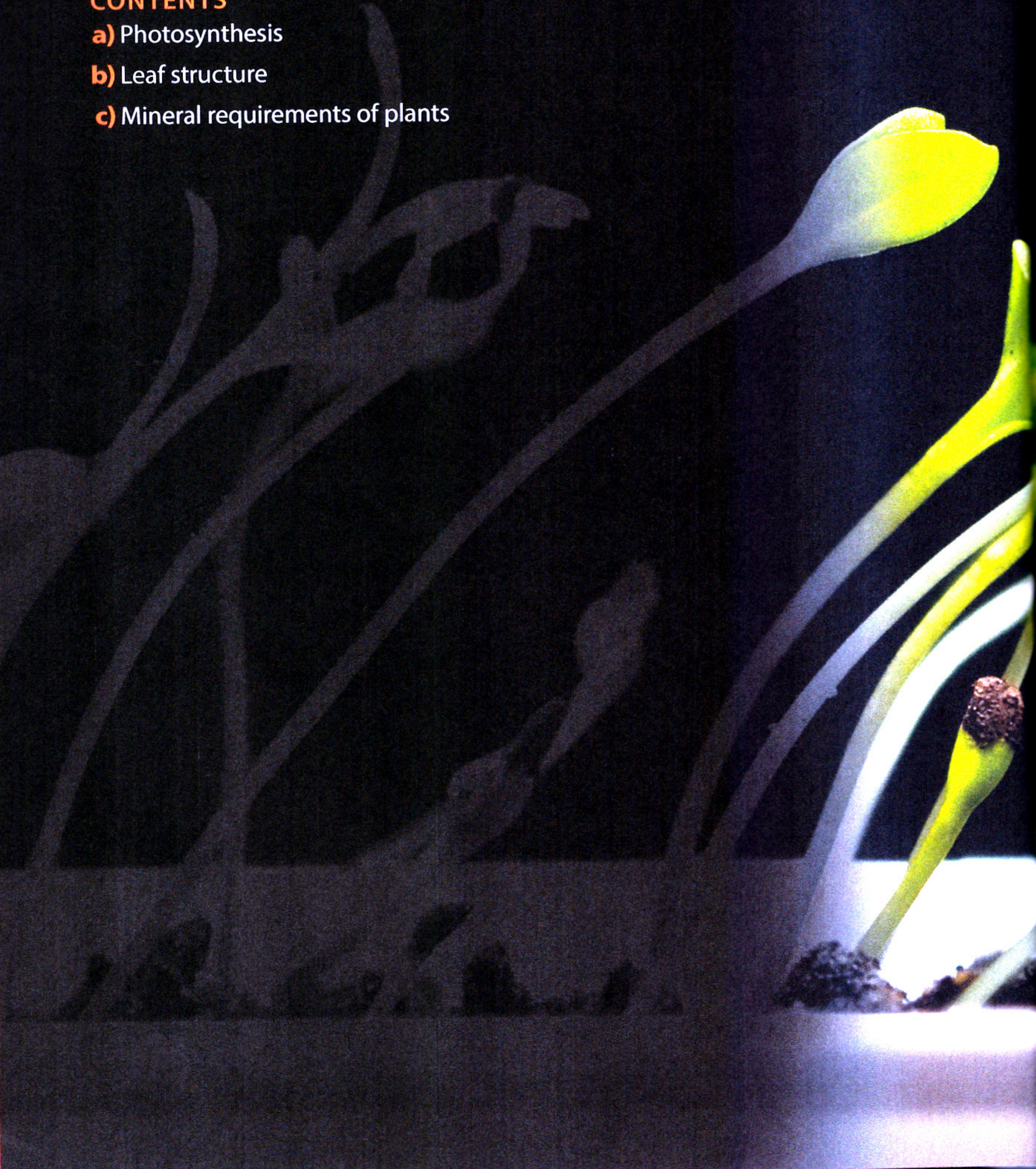
The world's tallest known living tree, which has been named Hyperion, is a coast redwood tree growing in Northern California in the US. When it was measured in 2006 it was found to be 115.61 m tall (379.3 ft). Like all plants, from the smallest seedling to the tallest redwood giant, Hyperion makes its own food from three simple ingredients, sunlight, water and carbon dioxide. This process is known as photosynthesis, and is one of the features of plants that distinguish them from animals.

CONTENTS

a) Photosynthesis

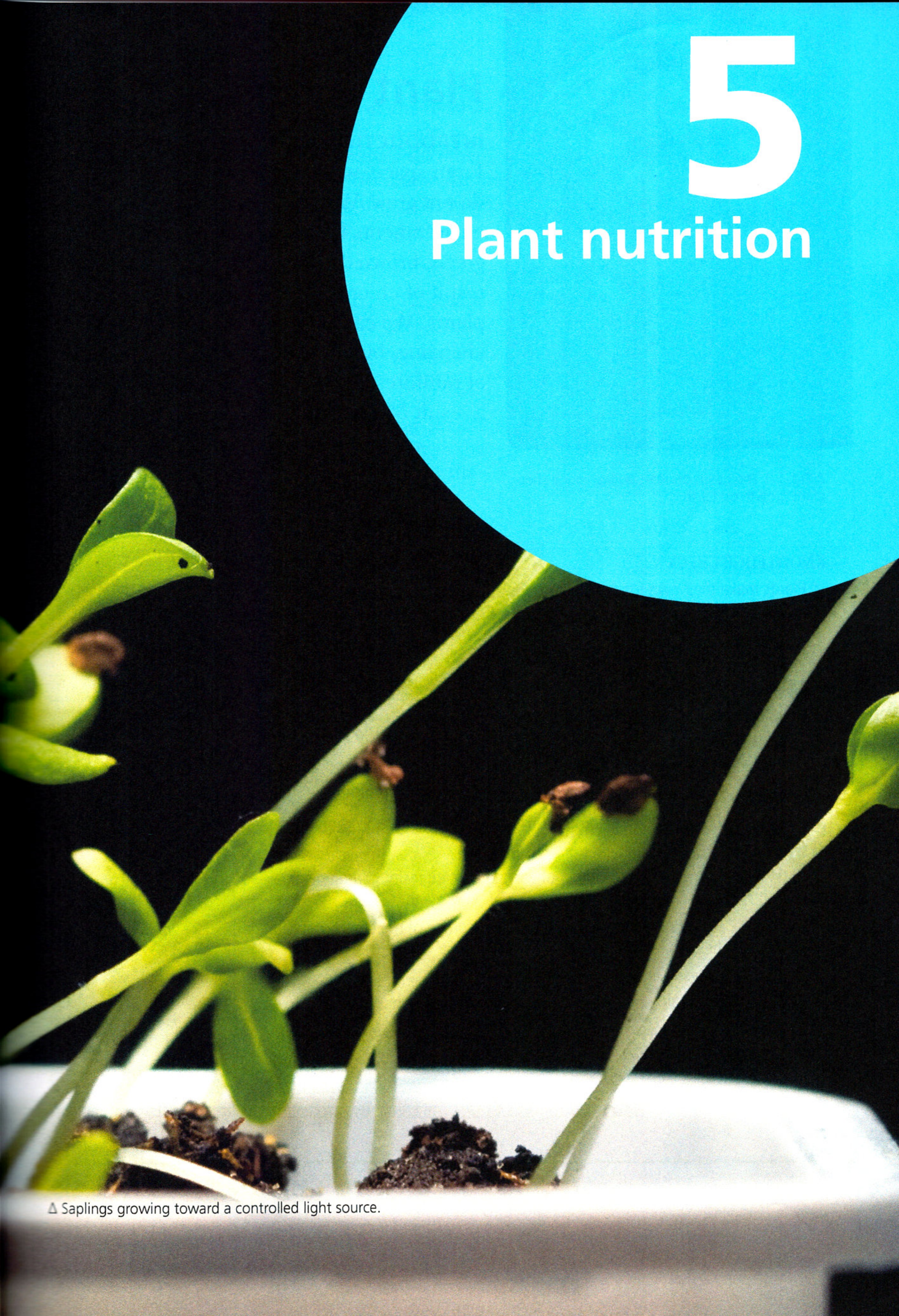
b) Leaf structure

c) Mineral requirements of plants



5

Plant nutrition



∆ Saplings growing toward a controlled light source.

Δ Fig. 5.1 The green on this satellite image shows plant growth on Earth.

Plant nutrition

INTRODUCTION

From space, we can see where plants do or do not grow. We can distinguish different environments by looking at where the land is green, brown or white. The green areas are a result of chlorophyll in photosynthesising plants. We can also see where land use is changing, by looking at how the green areas of rainforests are slowly becoming brown as a result of deforestation.

KNOWLEDGE CHECK

- ✓ Plants make their own food in their leaves using photosynthesis.
- ✓ Plant structures, such as the leaf and root cells, are adapted for their functions in nutrition.

LEARNING OBJECTIVES

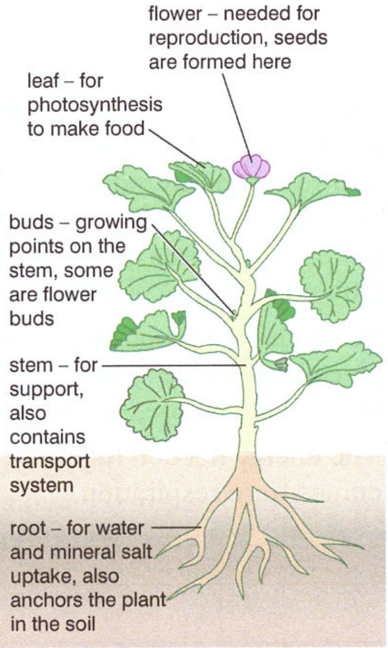
- ✓ Define the term *photosynthesis* and write the word equation for the reaction.
- ✓ Investigate the need for chlorophyll, light and carbon dioxide for photosynthesis, using appropriate controls.
- ✓ **EXTENDED** Write the balanced symbol equation for photosynthesis.
- ✓ **EXTENDED** Explain that chlorophyll transfers light energy into chemical energy in molecules, for the synthesis of carbohydrates.
- ✓ **EXTENDED** Investigate the effect of varying light intensity, carbon dioxide concentration and temperature on the rate of photosynthesis.
- ✓ **EXTENDED** Outline the subsequent use and storage of the carboydrates made in photosynthesis.
- ✓ Identify structures in leaves of a dicotyledonous plant.
- ✓ **EXTENDED** Explain how a leaf is adapted for photosynthesis.
- ✓ Describe the importance of nitrate ions and magnesium ions in plant growth.
- ✓ **EXTENDED** Explain the effect of the deficiency of nitrate ions and magnesium ions on a plant.

PHOTOSYNTHESIS

Plant tissue contains the same types of chemical molecules (carbohydrates, proteins and lipids) as animal tissue. However, whereas animals eat other organisms to get the nutrients they need to make these molecules, plants make these molecules from basic building blocks, beginning with the process of **photosynthesis**.

EXTENDED

In photosynthesis, plants combine the raw materials carbon dioxide (from the air) and water (from the soil) to form glucose, a simple sugar and also a carbohydrate. This process transfers energy from light (usually from sunlight) into chemical energy in the bonds of the glucose. The light is absorbed by the green pigment **chlorophyll** in plants.


flower – needed for reproduction, seeds are formed here
leaf – for photosynthesis to make food
buds – growing points on the stem, some are flower buds
stem – for support, also contains transport system
root – for water and mineral salt uptake, also anchors the plant in the soil

Δ Fig. 5.2 Anatomy of a plant.

END OF EXTENDED

Photosynthesis is fundamental to almost all life on Earth, because most organisms other than plants get their energy from the chemical energy in the food that they eat, whether that is herbivores getting energy directly from plants, or carnivores consuming herbivores.

Oxygen is also produced in photosynthesis. Although some is used inside the plant for respiration (releasing energy from food), most is not needed and is given out as a **waste product**.

The process of photosynthesis can be summarised in a word equation:

$$\text{carbon dioxide} + \text{water} \xrightarrow[\text{light energy}]{\text{chlorophyll}} \text{glucose} + \text{oxygen}$$

EXTENDED

Photosynthesis can also be summarised as a balanced symbol equation:

$$6CO_2 + 6H_2O \xrightarrow[\text{light energy}]{\text{chlorophyll}} C_6H_{12}O_6 + 6O_2$$

REMEMBER

You will need to know, and be able to balance, the chemical equation for photosynthesis.

END OF EXTENDED

EXTENDED

Much of the glucose formed by photosynthesis is converted into other substances, including **starch**. Starch molecules are large carbohydrates made of lots of glucose molecules joined together. Starch is insoluble and so can be stored in cells without affecting water movement into and out of the cells by **osmosis**. Some plants, such as potato and rice plants, store large amounts of starch in particular parts of the plant (tubers or seeds). We use these parts as sources of starch in our food.

Some glucose is converted to **sucrose** (a type of sugar formed from two glucose molecules joined together). This is still soluble, but not as reactive as glucose, so can easily be carried around the plant in solution.

The energy needed to join simple sugars to make larger carbohydrates comes from respiration.

END OF EXTENDED

QUESTIONS

1. Write the word equation for photosynthesis.
2. Explain the importance of light in photosynthesis.
3. EXTENDED **a)** Write the balanced symbol equation for photosynthesis.
   b) Annotate your equation to show where each of the reactants comes from, and each of the products goes to.
4. EXTENDED Explain why the transfer of energy from light to chemical energy in plant cells is essential for life on Earth.

SCIENCE LINK

CHEMISTRY – STOICHIOMETRY

- Photosynthesis is a chemical reaction, so links to ideas about word equations and balanced symbol equations.
- Remember that the formula for each compound is fixed, so to keep in line with the law of conservation of mass we need to think about the atoms in the complete molecules when balancing an equation.
- Photosynthesis is an example of an endothermic reaction.

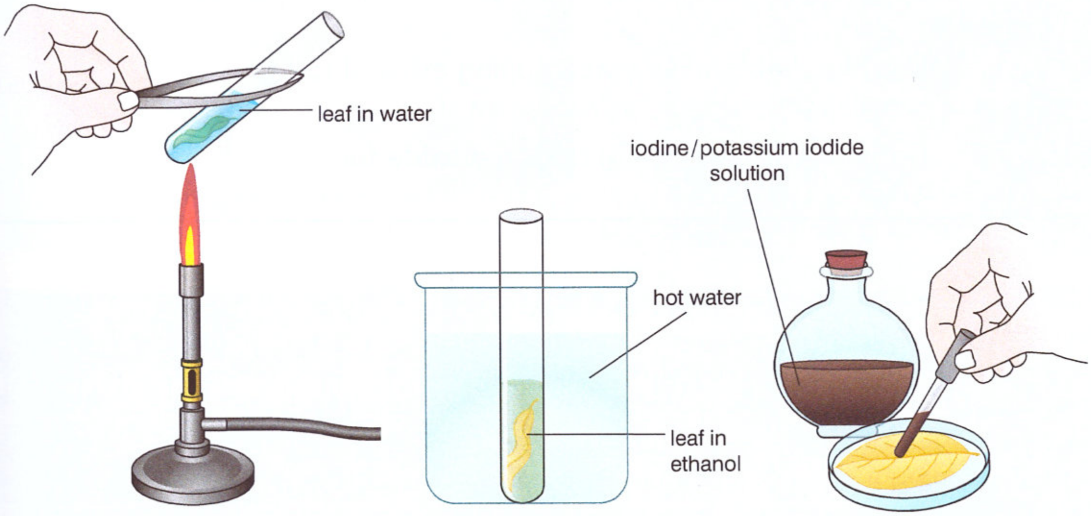
PHYSICS – PROPERTIES OF WAVES

- Photosynthesis requires the energy from light.
- The colours of visible light in the electromagnetic spectrum have different wavelengths. Some wavelengths are more useful in photosynthesis than others.

Investigating photosynthesis

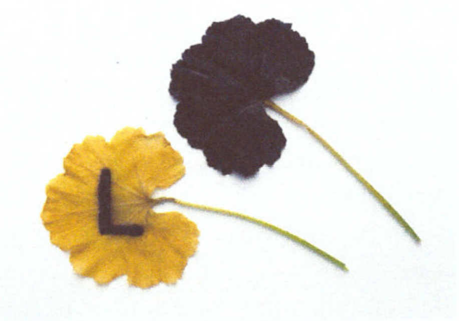
We can use the iodine test to show that photosynthesising parts of a plant produce starch. Before carrying out this test, though, we must start by leaving the plant in a dark place for 24 hours. This will make sure that the plant uses up its stores of starch (this is known as destarching) and means that any starch identified by the test is the result of photosynthesis during the investigation.

- The production of starch after photosynthesis can be shown simply by placing a destarched plant in light for an hour. Remove one leaf and place it in boiling water for a few minutes to soften it. Then place the leaf in boiling ethanol heated in a beaker of boiling water, not over a Bunsen because ethanol fumes are flammable. This removes the chlorophyll in the leaf. When the leaf has lost its green, wash it in cold water before placing it in a dish and adding a few drops of iodine solution. The leaf should turn blue–black, indicating the presence of starch.



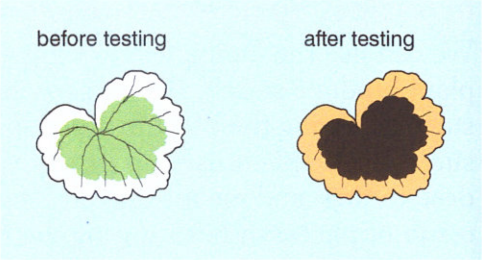
∆ Fig. 5.3 Preparing and testing a leaf for starch.

- The investigation above can be adjusted to show the need for light by covering part of the leaf before the destarched plant is brought into the light. Only the part of the leaf that received light should test positive for the presence of starch, showing that photosynthesis is linked to the production of starch.
- This investigation can also be adjusted to show the need for chlorophyll by using variegated leaves. Variegated leaves are partly green (where the cells contain chlorophyll) and partly white (where there is no chlorophyll). A variegated leaf after this investigation will show the presence of starch where there was chlorophyll but not in the parts of the leaf that had no chlorophyll.



∆ Fig. 5.4 Light was excluded from all of the lower leaf except an L-shaped window. After exposure to light, only the L shape tests positive for starch.

- A simple test to show the need for carbon dioxide can be carried out by setting up two bell jars on glass sheets. Sodium or potassium hydroxide reacts with carbon dioxide, removing it from the air. So, a dish of one of the hydroxides is placed in one bell jar. Carbon dioxide is added to the other bell jar by burning a candle in it, which also removes some of the oxygen. Similar destarched plants are placed in each bell jar, and the base of the jar sealed to the glass sheet, for example with petroleum jelly. After a few hours in light, a leaf from each plant is tested for starch, which should show that the plant with the least carbon dioxide produces little starch.



Δ Fig. 5.5 Only the green parts of a variegated leaf can photosynthesise, as shown by the leaf on the right, which has been tested for starch.

QUESTIONS

1. Describe a test that would show the need for chlorophyll in photosynthesis.
2. What precautions should be taken when boiling ethanol to remove chlorophyll in a leaf? Explain your answer.
3. How could you show that plants need carbon dioxide for photosynthesis?

EXTENDED

Investigating the rate of photosynthesis

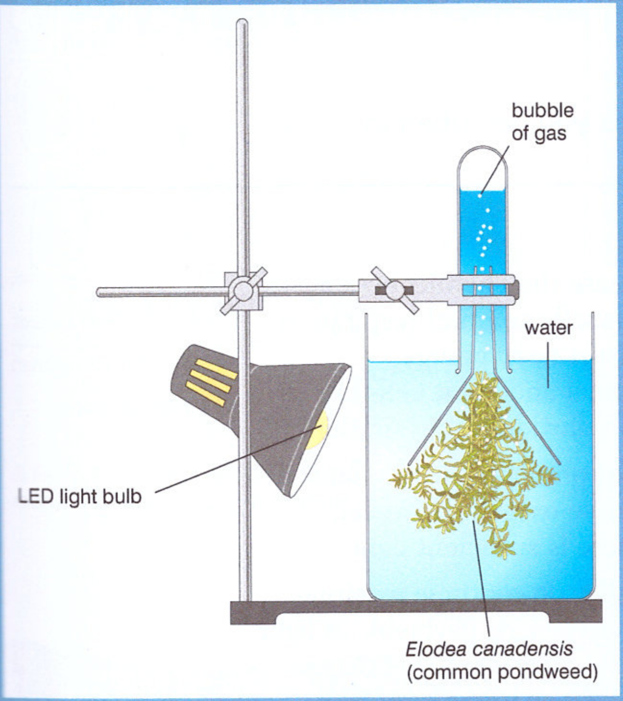
Measuring starch production is an indirect measurement of photosynthesis, because starch is made from the glucose produced in photosynthesis. You can investigate photosynthesis more directly by measuring the amount of oxygen produced by a plant. The oxygen is usually collected over water, and these investigations are most simply done using aquatic plants (plants that grow in water), such as pondweed, using the apparatus shown in the Developing investigative skills box on the following page.

- To prove that photosynthesis produces oxygen, simply use the glowing splint test on the gas collected. The splint should re-ignite, showing that the gas is oxygen.
- The investigation can be adjusted to test for the effect of light intensity on the rate of photosynthesis as described in the Developing investigative skills box.
- The investigation can be adjusted to test for the effect of carbon dioxide concentration by adding different amounts of sodium bicarbonate to the water and measuring the rate at which bubbles of oxygen are produced.
- The investigation can be adjusted to test for the effect of temperature by placing the beaker of pondweed in water baths of different temperatures and measuring the rate at which bubbles of oxygen are produced.

In each of these investigations, all other factors that may affect the rate of photosynthesis must be controlled and kept constant as far as possible.

Developing investigative skills

You can investigate the effect of light on photosynthesis by shining a light on a water plant and measuring how quickly bubbles are given off, as shown in Fig. 5.6.



Δ Fig. 5.6 Apparatus for the investigation into the effect of light on photosynthesis.

The results below were gathered using this apparatus.

	Distance to lamp/cm				
	5	10	15	20	25
Number of gas bubbles given off in 5 minutes	67	57	40	20	4

Devise and plan investigations

❶ **a)** Explain why the rate of bubble production can be used as a measure of the rate of photosynthesis.

b) Explain how you would identify the gas produced by the plant.

Analyse and interpret data

❷ **a)** Use the data in the table to draw a suitable graph.

b) Describe and explain the shape of the graph.

Evaluate data and methods

❸ Light is not the only factor that can affect the rate of photosynthesis.

a) Which other factor might have had an effect on these measurements.

b) Suggest how the method could be changed to avoid this problem.

QUESTIONS

1. Describe how each of the following factors affects the rate of photosynthesis.
    a) light intensity
    b) carbon dioxide concentration
    c) temperature
2. Explain why the factors have the effects you described in Question 1.

Gas exchange in plants

All organisms use cellular respiration to release the chemical energy in food molecules such as glucose. Cellular (usually aerobic) respiration must take place all the time because organisms need energy continuously for other life processes. So animal and plant cells are always taking in oxygen and releasing carbon dioxide for respiration.

Plants photosynthesise as well as respire. For photosynthesis, plant cells need to take in carbon dioxide and release oxygen. However, photosynthesis can only take place when there is sufficient light.

At night, plants do not photosynthesise, but they do continue respiring. So plants give out carbon dioxide and take in oxygen. At daybreak, as light intensity increases, the rate of photosynthesis increases. At a particular light intensity, the amount of oxygen produced by photosynthesis will balance the amount used by the plant in respiration, and the *net production of oxygen* will be zero. This is known as a compensation point.

During daylight, oxygen production from photosynthesis exceeds its use in respiration, and the opposite is true for the use (by photosynthesis) and production (by respiration) of carbon dioxide. This continues until light intensity decreases, when the sun sets and a second compensation point is reached.

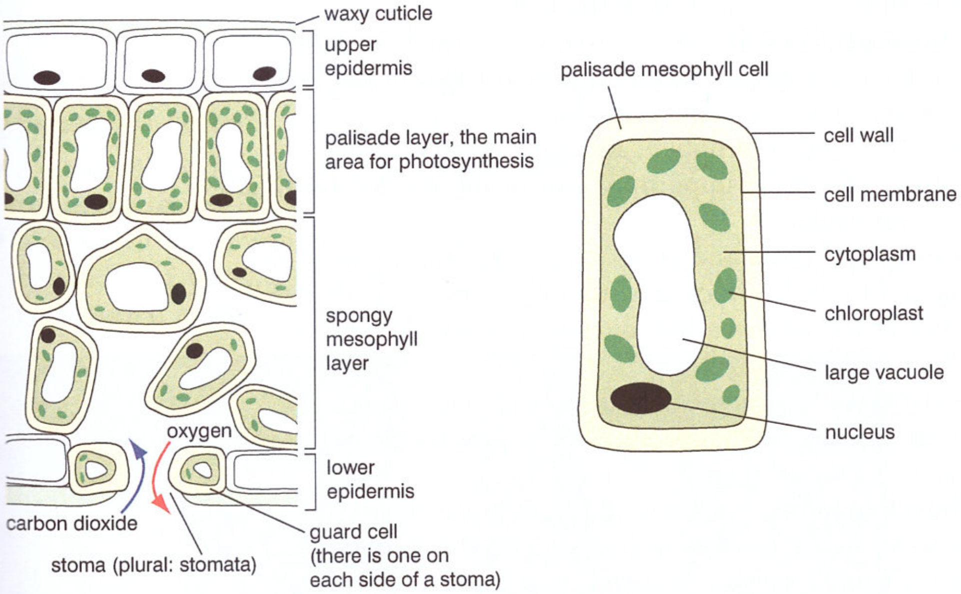
END OF EXTENDED

LEAF STRUCTURE

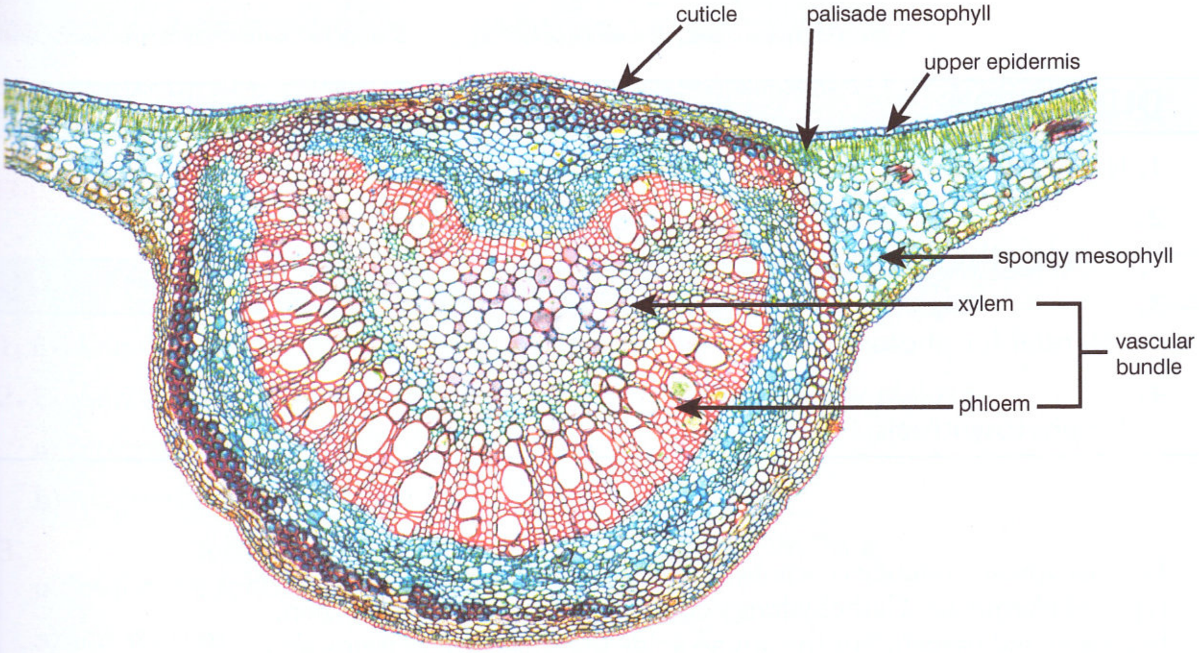
Photosynthesis takes place mainly in the leaves, although it can occur in any cells that contain green chlorophyll. Leaves are adapted to make them very efficient as sites for photosynthesis, gas exchange, transport and support.

▷ Fig. 5.7 The leaves of trees are often arranged so that they do not overlap each other, which makes it possible for the tree to capture as much light energy as possible.

Figure 5.8 shows the arrangement of cells and tissues inside a leaf.


waxy cuticle
upper epidermis
palisade layer, the main area for photosynthesis
spongy mesophyll layer
oxygen
lower epidermis
carbon dioxide
guard cell (there is one on each side of a stoma)
stoma (plural: stomata)
palisade mesophyll cell
cell wall
cell membrane
cytoplasm
chloroplast
large vacuole
nucleus

Δ Fig. 5.8 Cells in a section of a leaf (left), and a palisade mesophyll cell (right), which contains many chloroplasts, for photosynthesis.


cuticle
palisade mesophyll
upper epidermis
spongy mesophyll
xylem
phloem
vascular bundle

Δ Fig. 5.9 Photomicrograph of a section of a dicotyledonous plant leaf. Stomata are not easily seen in this section.

EXTENDED

Adaptations for photosynthesis

Many structures in a leaf are adapted so that photosynthesis can be carried out as efficiently as possible.

- The waxy **cuticle** that covers the leaf, particularly the upper surface, prevents the loss of water from epidermal cells and helps to stop the plant from drying out too quickly.

- The transparent upper **epidermis** allows as much light as possible to reach the photosynthesising cells within the leaf.
- The **palisade mesophyll cells**, where most photosynthesis takes place, are tightly packed together in the uppermost half of the leaf so that as many as possible can receive sunlight.
- **Chloroplasts**, containing chlorophyll, are concentrated in the palisade mesophyll cells in the uppermost half of the leaf to absorb as much sunlight as possible.
- The **spongy mesophyll cells** and air spaces in the lower part of the leaf provide a large internal surface-area-to-volume ratio to allow the efficient exchange of the gases carbon dioxide and oxygen between the cells and the air in the leaf.
- Many pores or **stomata** (singular: stoma) allow the movement of gases into and out of the leaf, to give efficient gas exchange between the leaf and the air surrounding it.
- The **vascular bundles** form the veins in the stem and leaf. The thick cell walls of the tissue in the bundles help to support the stem and leaf.
- **Phloem** tissue transports sucrose, formed from glucose in photosynthesising cells, away from the leaf. **Xylem** tissue transports water and minerals to the leaf from the roots.

END OF EXTENDED

QUESTIONS

1. Name four tissues in a leaf.
2. EXTENDED List as many adaptations of a plant leaf for photosynthesis as you can.
3. EXTENDED Explain why a large surface area inside the leaf is essential for photosynthesis.
4. EXTENDED Explain why a transparent epidermis is an adaptation for photosynthesis.

MINERAL REQUIREMENTS OF PLANTS

Photosynthesis produces carbohydrates, but plants contain many other types of chemicals. Carbohydrates contain just the elements carbon, hydrogen and oxygen, but the amino acids that make up proteins also contain nitrogen. So plants need a source of nitrogen. Other chemicals in plants contain different elements; for example, chlorophyll molecules contain magnesium and nitrogen. Without a source of magnesium and nitrogen, a plant cannot produce chlorophyll and so cannot photosynthesise.

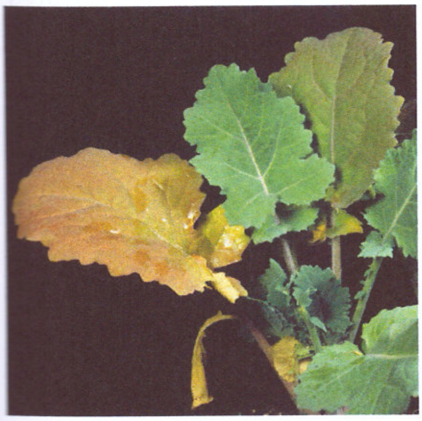
These additional elements are dissolved in water in the soil as **mineral ions**. Plants absorb mineral ions through their roots, using active transport because the concentration of the ions in the soil is lower than in the plant cells.

EXTENDED

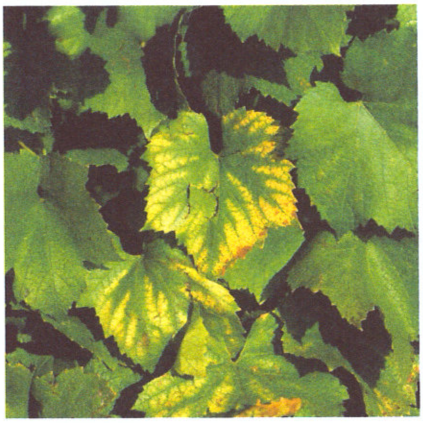
Mineral deficiencies

Plants that are not absorbing enough mineral ions show particular symptoms of deficiency. For example:

- a plant with a nitrate ion deficiency has stunted growth and yellowing leaves
- a plant with magnesium ion deficiency has leaves that are yellow between the veins, particularly in older leaves as the magnesium is transported in the plant to the new leaves.



Δ Fig. 5.10 A plant showing symptoms of nitrate ion deficiency.



Δ Fig. 5.11 A plant showing symptoms of magnesium ion deficiency.

END OF EXTENDED

QUESTIONS

1. Explain why plants need a supply of mineral ions.
2. Explain what plants use the following mineral ions for:
   - a) nitrogen ions
   - b) magnesium ions.
3. EXTENDED Describe and explain the deficiency symptoms in a plant for the following mineral ions:
   - a) nitrate ions
   - b) magnesium ions.

End of topic checklist

Key terms

chlorophyll, chloroplast, epidermis, mineral ion, palisade mesophyll cell, phloem, photosynthesis, spongy mesophyll cell, starch, stomata, xylem

During your study of this topic you should have learned:

○ How to define photosynthesis as the process by which plants make carbohydrates (glucose) from raw materials using light.

○ How to investigate the necessity of chlorophyll, light and carbon dioxide for photosynthesis, using appropriate controls.

○ **EXTENDED** That photosynthesis takes place in chloroplasts in plant cells, using chlorophyll, and converts light energy into chemical energy.

○ The word equation for photosynthesis:

$$\text{carbon dioxide} + \text{water} \xrightarrow[\text{light energy}]{\text{chloroplast}} \text{glucose} + \text{oxygen}$$

○ **EXTENDED** The balanced symbol equation for photosynthesis:

$$6CO_2 + 6H_2O \xrightarrow[\text{light energy}]{\text{chloroplast}} C_6H_{12}O_6 + 6O_2$$

○ **EXTENDED** How to outline the use and storage of the carbohydrates made in photosynthesis.

○ **EXTENDED** How to investigate the increase in the rate of photosynthesis as carbon dioxide concentration increases, as light intensity increases, and as temperature increases up to an optimum temperature, after which it decreases as enzymes denature.

○ That chloroplasts are found mainly in cells in the upper part of a leaf.

○ To identify the tissues that can be seen in leaves, including: cuticle, upper epidermis, lower epidermis including stomata and guard cells, palisade mesophyll cell, spongy mesophyll, phloem and xylem.

○ **EXTENDED** To explain how the leaf is adapted to maximise the rate of photosynthesis by:

- the cells where most photosynthesis takes place are in the palisade mesophyll near the upper surface of the leaf
- the transparent upper epidermis lets lots of light through
- the spongy mesophyll maximises the internal surface area of the leaf for diffusion
- stomata allow gases to diffuse into and out of the leaf and are opened and closed by guard cells
- xylem transports water to the leaf
- phloem transports sugars away from the leaf.

○ To describe how plants use mineral ions to convert the sugars from photosynthesis into other essential substances, such as chlorophyll, which contains magnesium, and amino acids, which contain nitrogen.

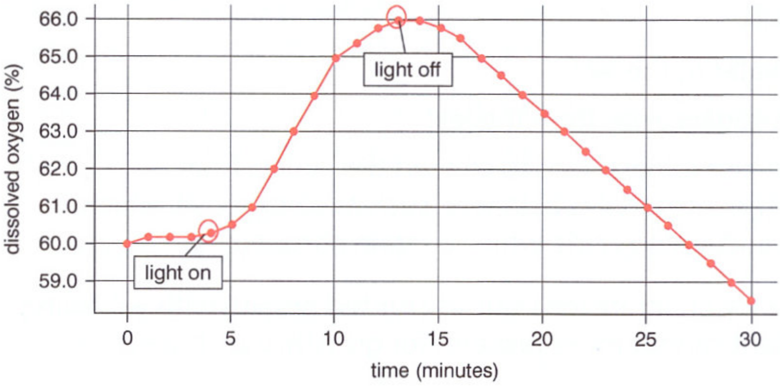
○ **EXTENDED** The deficiency of nitrate ions causes stunted growth with yellowing leaves, because the plant cannot make proteins for growth and chlorophyll.

○ **EXTENDED** The deficiency of magnesium ions causes yellowing leaves as the plant cannot make chlorophyll.

End of topic questions

Note: The marks given for these questions indicate the level of detail required in the answers. In the examination, the number of marks given to questions like these may be different.

1. Some students used an oxygen sensor to measure the amount of dissolved oxygen in pond water containing pondweed, when a light was on and when it was switched off. The graph shows their results.



a) The light was switched on after 4 minutes. Describe and explain what happened until the light was switched off again. **(2 marks)**

b) Describe and explain what happened after the light was switched off. **(2 marks)**

2. **EXTENDED** Explain why gardeners may add a liquid feed containing nitrogen and magnesium ions to the water for the plants that they are growing. **(2 marks)**

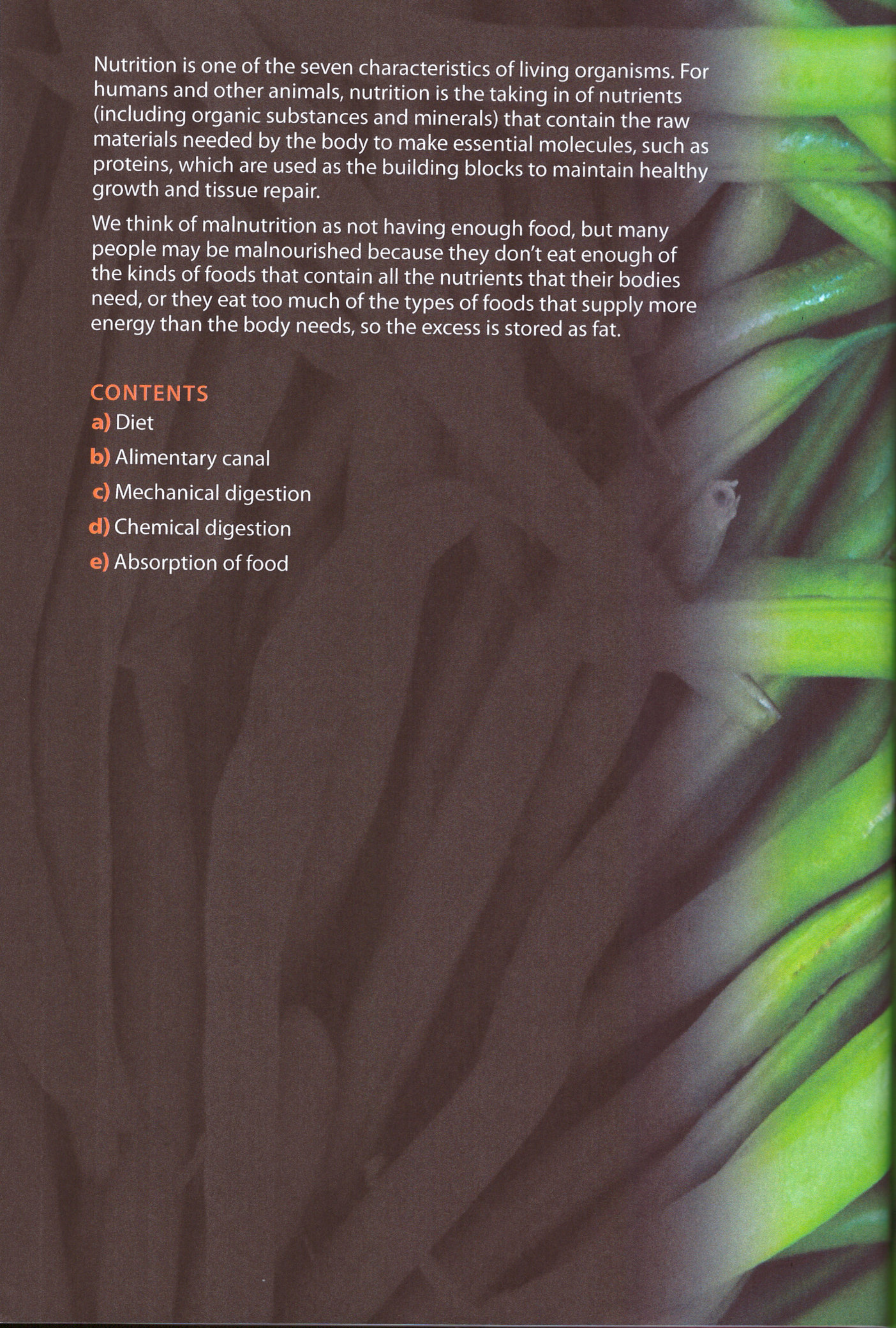
3. **EXTENDED** Using what have you learned about the effect of concentration gradient and surface-area-to-volume ratio, explain the adaptations of a leaf for photosynthesis. **(4 marks)**

4. **EXTENDED** Sketch the axes of a graph with time of day along the x-axis and rate of photosynthesis on the y-axis. The units on the x-axis should start at midnight on one day and end at midnight on the following day. Add an arrowhead at the top of the y-axis to show that the units are arbitrary (have no values) but increase as you go up the axis.

a) Draw a line on your graph to show how the rate of photosynthesis might change during the day for a large tree. **(1 mark)**

b) Annotate your graph to explain which factor (or factors) may be limiting the rate of photosynthesis at different times of day. **(3 marks)**

5. It is commonly stated that 'Plants produce oxygen during the day and carbon dioxide at night.' Explain fully the limits of this statement. **(5 marks)**



Nutrition is one of the seven characteristics of living organisms. For humans and other animals, nutrition is the taking in of nutrients (including organic substances and minerals) that contain the raw materials needed by the body to make essential molecules, such as proteins, which are used as the building blocks to maintain healthy growth and tissue repair.

We think of malnutrition as not having enough food, but many people may be malnourished because they don't eat enough of the kinds of foods that contain all the nutrients that their bodies need, or they eat too much of the types of foods that supply more energy than the body needs, so the excess is stored as fat.

CONTENTS

a) Diet

b) Alimentary canal

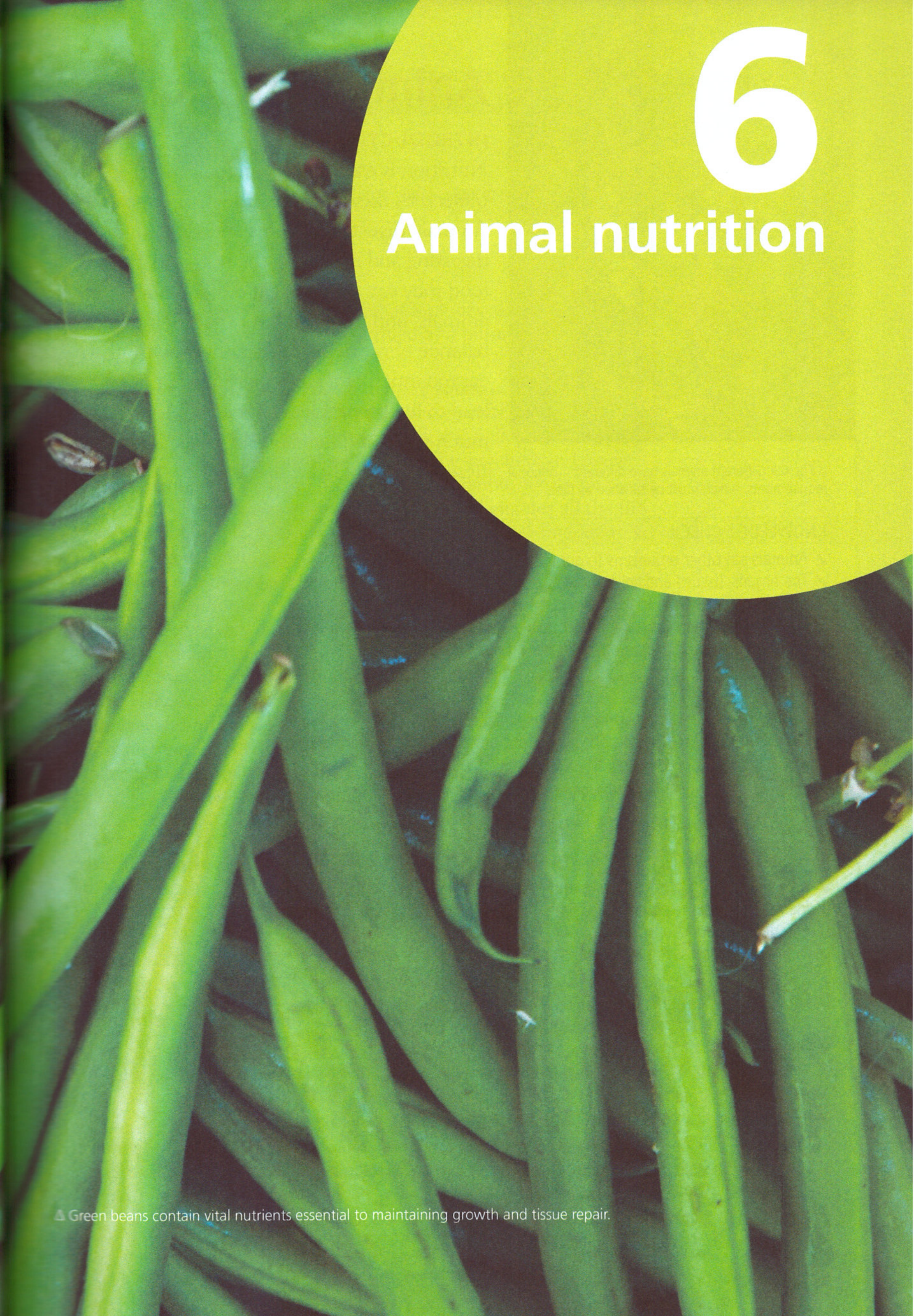
c) Mechanical digestion

d) Chemical digestion

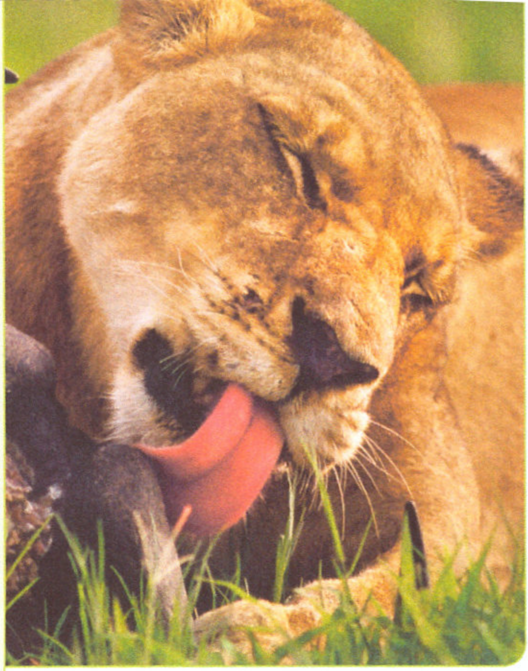
e) Absorption of food

6

Animal nutrition



▲ Green beans contain vital nutrients essential to maintaining growth and tissue repair.



△ Fig. 6.1 Different animals have different nutritional requirements, which must be satisfied by diet.

Animal nutrition

INTRODUCTION

Nutrition is essential for animals to get the molecules they need for growth and repair. Animals' digestive systems are adapted for digesting and absorbing the nutrients from the food they eat. Animals eat either plants or other animals, and it is important that their diet has a balance of nutrients for healthy growth. If we eat too much of a particular nutrient, it can lead to health problems, for example eating too much sugar and fat can lead to obesity and an increased risk of heart disease.

KNOWLEDGE CHECK

✓ Animals eat other organisms to get the food they need for their life processes.
✓ The organs, tissues and cells of the digestive system are adapted to digest and absorb nutrients from food.
✓ Food may be chemically or mechanically digested before absorption.
✓ Different groups of people need different diets.

LEARNING OBJECTIVES

✓ State what is meant by a *balanced diet* for humans.
✓ List the main sources of carbohydrates, fats, proteins, vitamins, minerals, fibre and water, and describe their importance in the diet.
✓ **EXTENDED** Explain how age, gender and activity affect the dietary needs of humans.
✓ **EXTENDED** Describe some effects of malnutrition in humans.
✓ **EXTENDED** Explain the causes and effects of vitamin D and iron deficiencies.
✓ **EXTENDED** Explain the causes and effects of protein energy malnutrition.
✓ Identify the main regions of the alimentary canal and associated organs, and describe their functions.
✓ Define the processes of *ingestion*, *digestion*, *absorption*, *assimilation* and *egestion*.
✓ **EXTENDED** Define *mechanical digestion* and *chemical digestion*.
✓ Identify the types of human teeth (incisors, canines, premolars and molars).
✓ Describe the structure of human teeth and gums.
✓ Describe the functions of the types of human teeth in mechanical digestion of food.
✓ Describe the proper care of teeth in terms of diet and regular brushing.
✓ **EXTENDED** State the causes of dental decay.
✓ State the significance of chemical digestion in the alimentary canal in producing small, soluble molecules that can be absorbed.
✓ **EXTENDED** State the functions of the enzymes amylase, protease and lipase and state where in the alimentary canal they are secreted.
✓ **EXTENDED** State and explain the functions of hydrochloric acid in gastric juice.

✓ EXTENDED Outline the role of bile in neutralising acid and emulsifying fats.

✓ EXTENDED Explain the significance of villi in increasing the internal surface area of the small intestine.

✓ EXTENDED Describe the structure of a villus.

✓ EXTENDED Describe the roles of capillaries and lacteals in villi.

DIET

Essential nutrients

To keep healthy, humans need a diet that includes all the nutrients that our cells and tissues use. This is described as a **balanced diet** and includes:

- **proteins** – these are broken down to make amino acids. The amino acids are used to form other proteins needed by cells, including enzymes. Protein sources include eggs, milk and milk products (cheese, yoghurt, etc.), meat, fish, legumes (peas and beans), nuts and seeds.
- **carbohydrates** – which are broken down to simple sugars for use in respiration. This releases energy in our cells and enables all the life processes to take place. Good sources of carbohydrate include rice, bread, potatoes, pasta and yams.
- **fats** – these are deposited in many parts of the body, including just below the skin. Some fat helps to maintain body temperature. Fat is also a store of energy to supply molecules for respiration, if the diet does not contain enough energy for daily needs. Fat is present in meat and can also come in the form of oils, milk products (butter, cheese), nuts, avocados and oily fish.
- **vitamins** and **minerals** – these substances are needed in tiny amounts for the correct functioning of the body. Vitamins and minerals cannot be produced by the body, and cooking food destroys some vitamins. For example, vitamin C is best supplied by eating raw fruit and vegetables.

Essential vitamins and minerals	**Job**	**Good food source**	EXTENDED **Deficiency disease**
vitamin C	for healthy skin, teeth and gums, and keeps lining of blood vessels healthy	citrus fruit, green vegetables, potatoes	scurvy (bleeding gums and wounds do not heal properly)
vitamin D	for strong bones and teeth	fish, eggs, liver, cheese and milk	rickets (softening of the bones)
calcium	needed for strong teeth and bones, and involved in the clotting of blood	milk and eggs	rickets
iron	needed to make haemoglobin in red blood cells	red meats, liver and kidneys, leafy green vegetables such as spinach	anaemia (reduction in number of red blood cells, person soon becomes tired and short of breath)

▲ Table 6.1 Vitamins and minerals, their roles, sources and effects of deficiency.

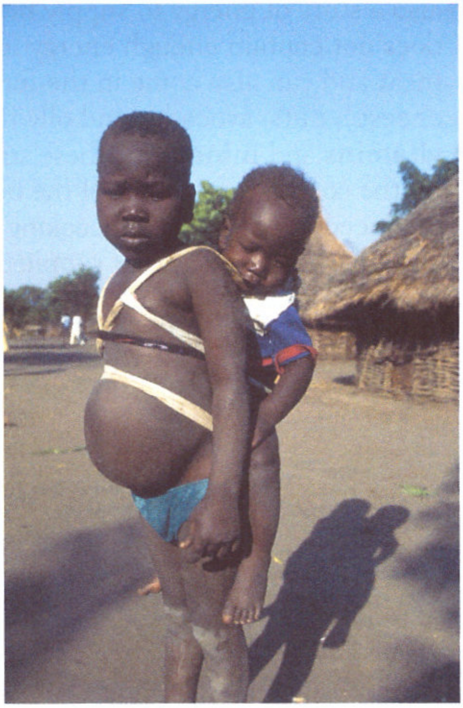
Δ Fig. 6.2 A healthy meal contains a good balance of the foods your body needs and nothing in too large an amount.

- **fibre (roughage)** – which is made up of the cell walls of plants. Good sources are leafy vegetables, such as cabbage, and unrefined grains, such as brown rice and wholegrain wheat. It adds bulk to food so that it can be easily moved along the digestive system by peristalsis. This is important in preventing constipation. Fibre is thought to help prevent bowel cancer.
- **water** – which is the major constituent of the body of living organisms and is necessary for all life processes. Water is continually being lost through excretion and sweating, and must be replaced regularly through food and drink in order to maintain health. Most foods contain some water, but most fruit and vegetables contain a lot of water.

EXTENDED

Kwashiorkor

Kwashiorkor is a condition found in young children in areas where the diet contains very little protein. The condition typically occurs in children who had been breast-fed but then are weaned after the birth of another baby. Breast milk contains proteins, but after weaning the child may get a carbohydrate-rich diet that includes few proteins and which is often lacking in some vitamins and minerals. So kwashiorkor is often referred to as **protein energy malnutrition**. Typical symptoms include swelling of the feet and abdomen, wasting muscles, thinning hair and loss of teeth. The liver is often damaged, and treatment requires careful adjustment of the diet so as not to damage the liver even more.



Δ Fig. 6.3 A child suffering from kwashiorkor, a protein deficiency.

Marasmus

Marasmus is a similar condition in very young children and is caused by a diet low in all energy-containing foods, not just protein. Children are short for their age and have a wasted appearance due to very low body fat and muscle. It can be fatal due to complications with dehydration, leading to heart problems and infections.

END OF EXTENDED

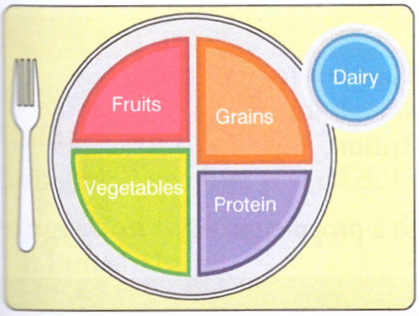
QUESTIONS

1. Give examples of foods that are good sources of each group of food molecules.
2. Which other substances are needed in our diet?
3. Explain the role of each of these substances in our diet.
4. EXTENDED Describe the causes and effects of kwashiorkor.

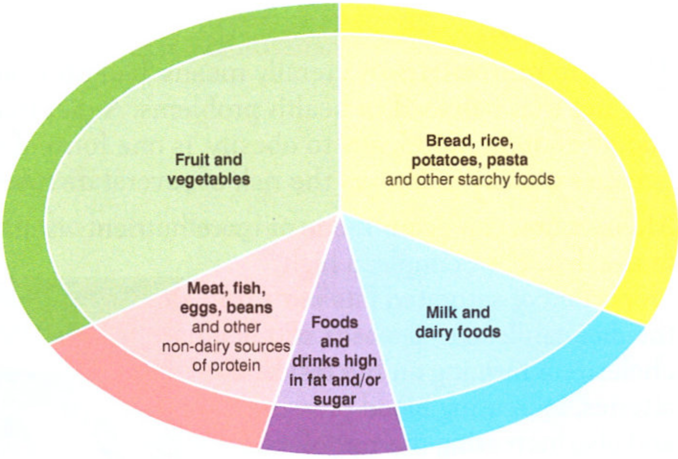
EXTENDED

The right balance

A balanced diet contains all of these nutrients in the right proportions to stay healthy because we need more of some nutrients than of others. As most foods contain more than one kind of nutrient, trying to work out what a balanced diet looks like can be difficult. Governments use images like the ones in Figs. 6.4 and 6.5, of food on a plate, to guide people on what proportions of food to eat.



Δ Fig. 6.4 Guidance from the USDA (United States Department of Agriculture) on the proportions of different nutrients in a balanced diet.



Δ Fig. 6.5 Guidance from the UK Government on the proportions of different nutrients in a balanced diet.

Different groups of people may have different needs for nutrients at different times in their lives, so this balance can change. For example, children need a higher proportion of protein than adults because they are still growing rapidly. Also, some groups of people have a greater need for a specific nutrient. During pregnancy, for example, a woman needs more iron than usual, to supply what the growing baby needs for making blood cells.

Even with the right proportions of nutrients in our foods, we can still be eating an unhealthy diet. This is because many of our foods, particularly carbohydrates but also fats and proteins, can contribute to the energy our bodies need. If we eat food that supplies more energy than we use, the extra will be deposited as energy stores of fat. This can lead to **obesity**, which is related to many health problems, such as heart disease and diabetes. Controlling the portion size at each meal, keeping between-meal snacks to a minimum, and increasing levels of exercise can help to reduce the risk of becoming overweight.

Energy requirements depend on body size, stage of development and level of exercise, as shown in Table 6.2.

	Energy used in a day (kJ)	
	Male	**Female**
6-year-old child	7 500	7 500
12–15-year-old teenager	12 500	9 700
adult manual worker	15 000	12 500
adult office worker	11 000	9 800
pregnant woman		10 000
breastfeeding woman		11 000

Δ Table 6.2 Daily energy requirements for different people.

Malnutrition

The term **malnutrition** literally means 'bad nutrition' and applies to any diet that will lead to health problems. A diet that is too high in energy content, and leads to obesity, is one form of malnutrition, because obesity increases the risk of several diseases.

Malnutrition can occur if one or more nutrients is in too high a proportion in the diet. For example, a high proportion of saturated fats in the diet can lead to deposits of cholesterol forming on the inside of arteries, increasing blood pressure and also increasing the risk of coronary heart disease (see Topic 7).

Malnutrition also occurs if any of the substances needed for a healthy body are in too low a proportion in the diet. For example, a lack of a vitamin or a mineral can cause deficiency diseases, as shown in Table 6.1. Too little fibre in the diet can lead to **constipation**, in which food moves too slowly through the **alimentary canal**, increasing the risk of diseases such as diverticulitis and bowel cancer.

Δ Fig. 6.6 Starvation is most commonly seen in places where crops have failed due to drought (**famine**) or people are displaced as a result of war. However, it can also happen in people who choose to starve themselves, in crash diets or as a result of conditions such as anorexia.

Starvation occurs when there is too little energy provided by the diet. In this state, the body will start to break down its energy stores. Initially this uses the fat stores but, when those have run out, the body will start to break down muscle tissue to produce substances that can be used in respiration. This can damage the muscle tissue of the heart, and also the immune system, increasing the risk of many diseases.

QUESTIONS

1. EXTENDED Explain why different groups of people need different amounts of nutrients. Give examples in your answer.
2. EXTENDED Explain why someone wishing to follow a healthy diet needs to consider energy as well as nutrients.
3. EXTENDED Explain why the following are considered to be a result of *malnutrition*:

   a) obesity

   b) starvation

   c) constipation.

END OF EXTENDED

ALIMENTARY CANAL

Eating food involves several different processes:

- **ingestion** – taking food and drink into the body (through the mouth in humans)
- **digestion** – breaking down of large food molecules into smaller water-soluble molecules using mechanical and chemical processes
- **absorption** – movement of small food molecules through the wall of the intestine into the blood
- **assimilation** – movement of digested food molecules into cells, where they can be used to produce other molecules or in respiration
- **egestion** – passing out of food that has not been digested through the anus as **faeces**.

All these different processes take place in different parts of the alimentary canal.

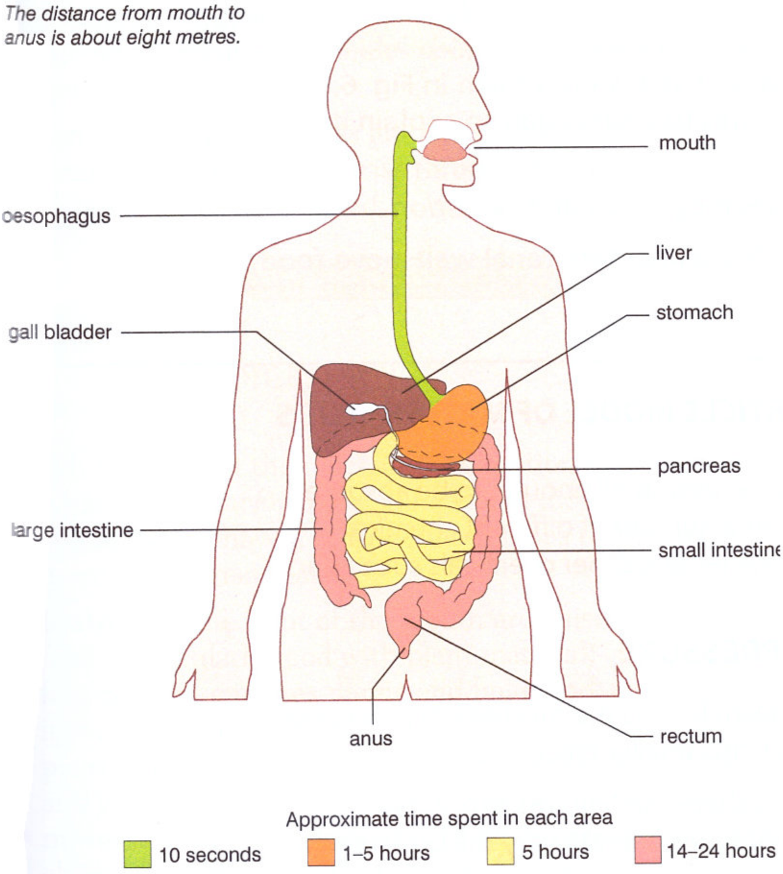
The alimentary canal is a continuous tube through the body, from the mouth where food is ingested, through the oesophagus, stomach, small intestine and large intestine, to the anus where faeces are egested. You could say that materials in the alimentary canal aren't truly in the body. Not until food molecules are absorbed, do they cross cell membranes into body tissue. Then they can be assimilated and **waste products** *excreted* through other organs.

The digestive system includes the alimentary canal and the other organs that contribute to digestion, such as the liver, pancreas and gall bladder. Table 6.3 describes the functions of each of the organs in the digestive system.

Part of digestive system	**Functions**
mouth	teeth and tongue break down food into smaller pieces
salivary glands	produce liquid saliva, which moistens food so it is easily swallowed and contains the enzyme amylase to begin breakdown of starch
oesophagus	each lump of swallowed and chewed food, called a bolus, is moved from the mouth to the stomach, via the oesophagus, by waves of muscle contraction called peristalsis
stomach	acid and protease enzymes are secreted to start protein digestion; movements of the muscular wall churn up food into a liquid
liver	cells in the liver make bile; amino acids not used for making proteins are broken down to form **urea**, which passes to the kidneys for excretion; excess glucose is removed from the blood and stored as **glycogen** in liver cells
gall bladder	stores bile from the liver; the bile is passed along the bile duct into the small intestine, where it neutralises the stomach acid in the chyme
pancreas	secretes digestive enzymes in an alkaline fluid into the small intestine
small intestine	secretions from the gall bladder and pancreas enter the first part of the small intestine to complete the process of digestion; digested food molecules and water are absorbed in the second part of the small intestine
large intestine	water is absorbed from the remaining material
anus	faeces are egested through a sphincter

Δ Table 6.3 The functions of parts of the human digestive system.

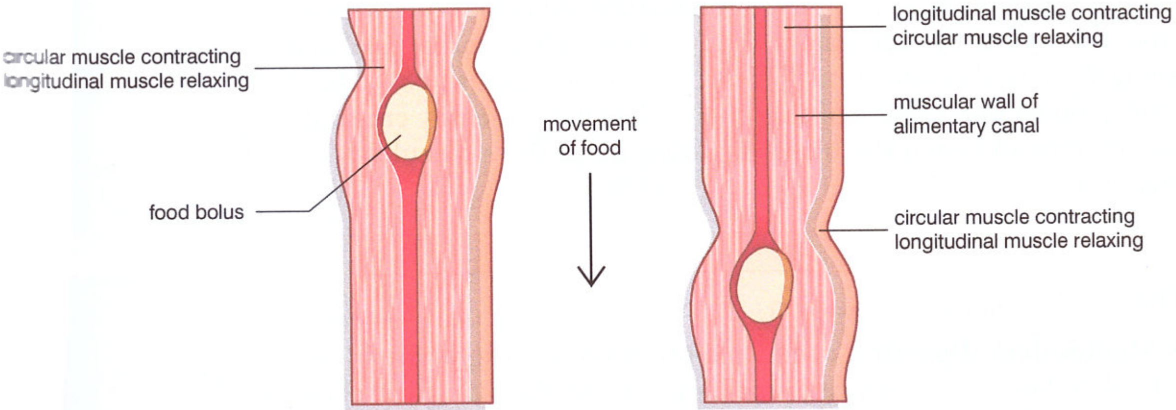
The distance from mouth to anus is about eight metres.


mouth
oesophagus
liver
stomach
gall bladder
pancreas
large intestine
small intestine
anus
rectum
Approximate time spent in each area
🟩 10 seconds
🟧 1–5 hours
🟨 5 hours
🟥 14–24 hours

▲ Fig. 6.7 The human digestive system.

Food moves along the alimentary canal because of the contractions of the muscles in the walls of the alimentary canal. This is called **peristalsis**. Fibre in the food keeps the bolus bulky and soft, making peristalsis easier.

Peristalsis moves food along the digestive system.


circular muscle contracting
longitudinal muscle relaxing
food bolus
movement of food
longitudinal muscle contracting
circular muscle relaxing
muscular wall of alimentary canal
circular muscle contracting
longitudinal muscle relaxing

▲ Fig. 6.8 Peristalsis moves food along the digestive system.

QUESTIONS

1. Sketch the diagram of the digestive system shown in Fig. 6.8. Label the organs, and add notes to each organ to explain its function in the system.
2. Explain the difference between *egestion* and *excretion*.
3. Explain how the muscles of the alimentary canal wall move food.

SCIENCE LINK

CHEMISTRY – PARTICLE MODEL OF MATTER, ACIDS

- Breaking down food into molecules small enough to be absorbed into the bloodstream involves a number of different chemical reactions, making use of enzymes and other chemicals such as acid in the stomach.

PHYSICS – FORCES AND PRESSURE

- An early stage in breaking down food is the mechanical process of biting and chewing the food into smaller pieces.
- Different teeth have different shapes to help the process in particular ways – the different types of teeth vary the pressure on the food and help with different actions such as cutting, gripping and grinding.

Different types of digestion

If food is to be of any use to us, the food molecules must enter the blood so that they can travel to every part of the body. Many of the foods we eat are made up of large, **insoluble** molecules that cannot cross the wall of the alimentary canal and the cell membranes of cells lining the blood vessels. This means the food molecules have to be broken down into small, **soluble** molecules that can easily cross cell membranes and enter the blood. Breaking down the molecules is called digestion.

EXTENDED

There are two types of digestion.

- **Mechanical digestion** occurs mainly in the mouth, where food is broken down physically into smaller pieces by the biting and chewing action of the teeth, without chemical change to the food molecules. It also happens in the small intestine, where **bile** helps to emulsify fats, which means breaking them into small droplets.

- **Chemical digestion** is the breakdown of large insoluble molecules into small, soluble molecules using chemicals such as enzymes (see Topic 5).

  Some molecules, such as glucose, vitamins, minerals and water, are already small enough to pass through the alimentary canal wall and do not need to be digested.

END OF EXTENDED

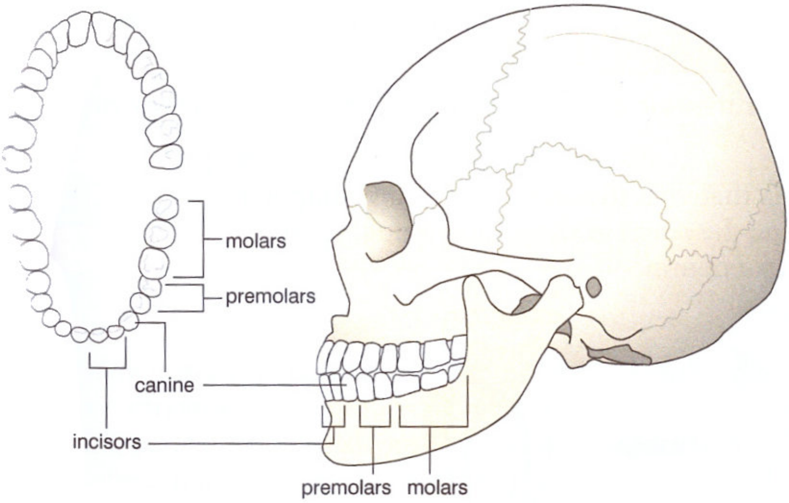
MECHANICAL DIGESTION

Human teeth

Teeth bring about the mechanical digestion of food in the mouth. Humans are omnivores that eat a varied diet of plant and animal material. So we have a range of tooth types to help us bite off and chew these different materials:

- **incisors** at the front of the mouth are chisel-shaped, for biting off food (particularly good with plant material)
- four pointed **canines** pierce and hold food, particularly meat, so that it can be chewed
- **premolars** help with the cutting off of tough foods, such as meat, and grinding of plant material on a small grinding surface
- **molars** at the back of the mouth have large grinding surfaces for chewing, particularly plant material.

In each adult jaw, we have four incisors, two canines, four premolars and between four and six molars.

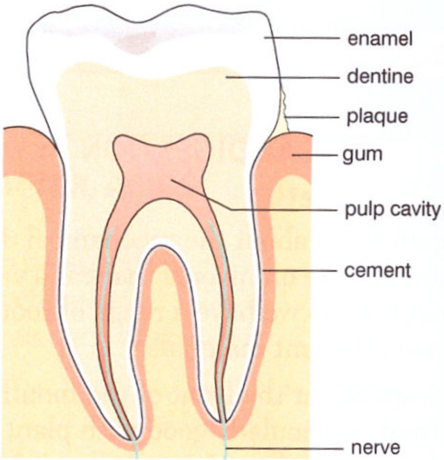


▲ Fig. 6.9 Plan and side view of teeth in a human skull.

Like other mammals, humans have two sets of teeth: the 'milk' teeth of childhood are replaced by permanent (adult) teeth from the age of about 6 years. The molars at the far back of the mouth, sometimes called the 'wisdom teeth', may not grow until adulthood, if at all.

Dental decay and tooth care

Although **enamel** is very hard, it is vulnerable to attack by acids. Acids are naturally present in fruits and other foods. Bacteria living in the spaces between teeth, in crevices on the tooth surface, and at the edges of the gums also make acids. Food particles get lodged in these crevices and bacteria grow on them, forming plaque. Plaque makes it even easier for bacteria to grow and produce acids right against the surface of the teeth. These acids corrode the tooth enamel and expose the softer **dentine** underneath. This can cause pain (or toothache) when the nerves in the **pulp cavity** are affected by acid, heat or cold. The enamel on teeth does not extend far below the gum edge, so when plaque forms there the dentine can quickly be attacked. The links between the tooth and its socket can be weakened and the tooth might fall out.


enamel
dentine
plaque
gum
pulp cavity
cement
nerve

Δ Fig. 6.10 The structure of a molar tooth.

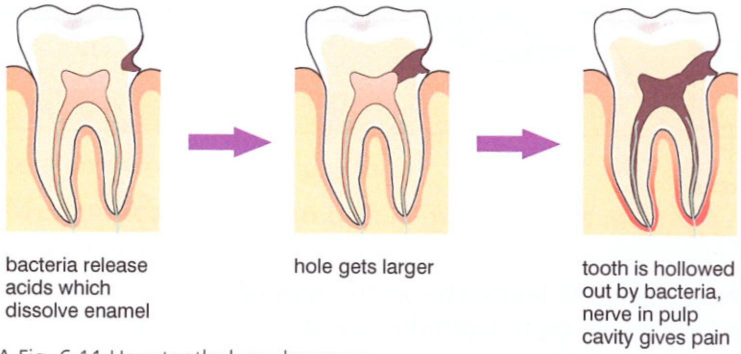
Brushing your teeth regularly helps to remove any build-up of plaque, and also any bits of food stuck between the teeth or at the edge of the gum. Toothpaste is used as well as the brush and has several benefits:

- It is alkaline and so neutralises acids near the teeth.
- It contains antibacterial substances such as mint.
- It usually contains a mild abrasive that helps to remove plaque.
- It may contain **fluoride**, which helps to strengthen enamel and reduce acidic damage.

EXTENDED

Causes of dental decay

Teeth can decay when bacteria that coat the teeth break down trapped food. The bacteria respire using the sugar in the food, producing an acid which dissolves enamel and dentine.

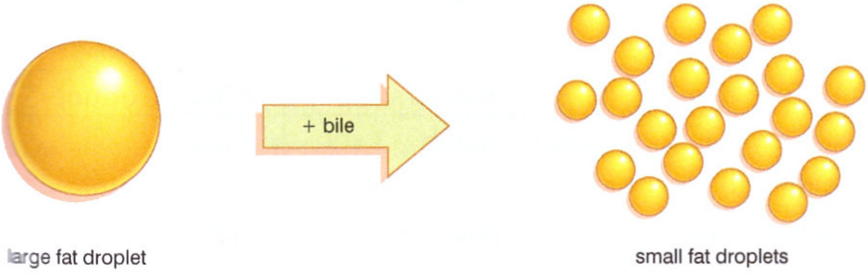

bacteria release acids which dissolve enamel
hole gets larger
tooth is hollowed out by bacteria, nerve in pulp cavity gives pain

Δ Fig. 6.11 How tooth decay happens.

Bile in digestion

Bile is a substance produced by cells in the liver. It is stored in the gall bladder until it is needed and then passes along the bile duct into the small intestine.

Bile is important in the digestion of fats. Fats do not mix well with aqueous (water-based) mixtures such as the digesting food, and so remain as large droplets. This gives a small surface area for lipase enzymes to work on, which slows down the rate of digestion. Bile **emulsifies** fats, breaking them up into much smaller droplets, so that the surface area is increased and rate of digestion is much faster.



△ Fig. 6.12 Bile lowers the surface tension of large droplets of fat so that they break up. This part of the digestive process is called emulsification.

END OF EXTENDED

QUESTIONS

1. EXTENDED Explain the difference between *chemical* and *mechanical* digestion.
2. Describe the different tooth types in a human mouth and explain how their different structures are related to their functions.
3. Explain why regular brushing of teeth helps prevent tooth decay.
4. EXTENDED Explain the role of bile in digestion.

EXTENDED

CHEMICAL DIGESTION

Chemical digestion in the alimentary canal is the result of enzymes. **Digestive enzymes** are a group of enzymes that are produced in the cells lining parts of the digestive system and are **secreted** (delivered) into the alimentary canal to mix with the food.

The digestive enzymes include:

- carbohydrases that break down carbohydrates, one example of which is **amylase**
- **proteases**
- **lipases**.

REMEMBER

The -ase at the end of the name means a substance is an enzyme, and the first part usually names the substrate that the enzyme works on.

Each of the food groups (carbohydrates, proteins and fats) contains many different molecules. As each enzyme is specific to its substrate, this means that in each group of digestive enzymes there are many different enzymes.

Different enzymes are made in different parts of the digestive system, as shown in Table 6.4.

Enzyme	Where produced	Substrate	Final products*
amylase	salivary glands (mouth) pancreas	starch	glucose
protease (many types)	stomach wall pancreas	proteins	amino acids
lipase (many types)	pancreas	fats and oils (lipids)	fatty acids and glycerol

Δ Table 6.4 Digestive enzymes.

*These are the soluble substances produced at the end of digestion. The substances in food and drink may go through many stages of digestion by different enzymes as they pass through the alimentary canal.

SCIENCE IN CONTEXT

LACTOSE

Lactose (from *lactis*, meaning 'milk') is the disaccharide sugar in milk, which is broken down in the alimentary canal by the enzyme **lactase** to the simple sugars glucose and galactose.

Like all young mammals, human babies produce lactase, which helps them to digest the lactose in breast milk. In most mammals, the production of lactase decreases as the young mature, because the adult diet does not include milk. This also happens in adults from many human cultures in which adults generally do not drink milk, such as in South-East Asia. However, there are human cultures in Europe, India and parts of East Africa, where mammals such as sheep, goats or cattle are kept to supply meat and milk for food. In these human groups, the adults continue to produce lactase and are able to digest the lactose in milk. Adults who cannot do this are *lactose intolerant*. In these people, bacteria in the alimentary canal break down the lactose, producing gas, which causes great discomfort.

The right conditions

Remember that different enzymes work better in different conditions (see Topic 4). Those enzymes that digest food in the stomach work best in acid conditions. Special cells in the lining of the stomach secrete hydrochloric acid into the stomach to create the right conditions for the enzymes. In particular, it gives the optimum pH for protease activity. The acid is also helpful in killing microorganisms taken in with the food.

This happens because the low pH denatures enzymes in the microorganisms so that they cannot function properly.

In the small intestine, the enzymes from the pancreas work best at slightly alkaline conditions. So the acidic food mix that enters the small intestine from the stomach has to be neutralised. Bile is highly alkaline, so when it is added to the contents of the small intestine it neutralises the acid from the stomach and makes the digesting food slightly alkaline.

QUESTIONS

1. **EXTENDED** Explain why enzymes are needed in the digestive system.
2. **EXTENDED** **a)** Which enzyme has starch as its substrate?

   b) Which product is formed by the digestion of starch by this enzyme?
3. **EXTENDED** Describe the roles of

   a) stomach acid

   b) bile in digestion.

END OF EXTENDED

ABSORPTION OF FOOD

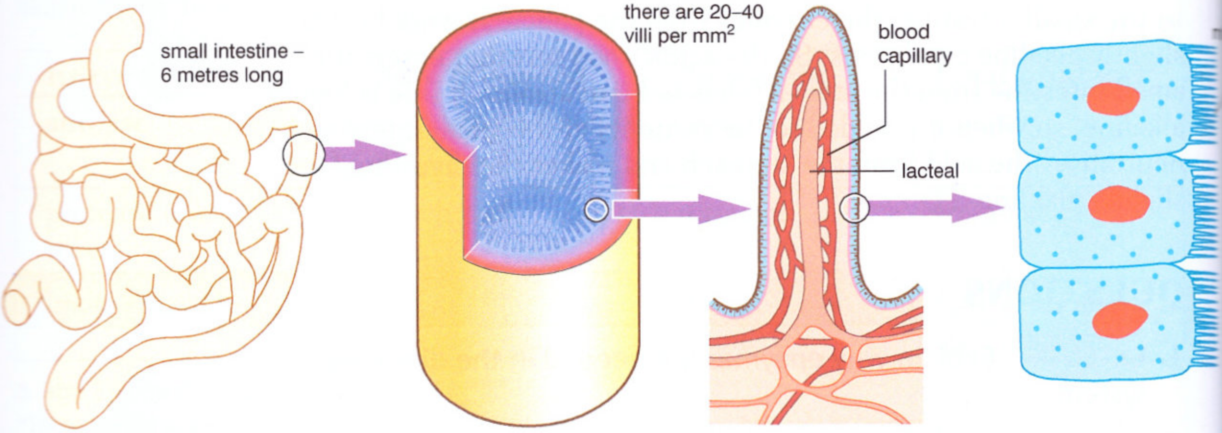
After food has been digested in the first part of the small intestine, small food molecules can diffuse across the intestinal wall and be absorbed into the body.

About 80% of water in the contents of the small intestine is also absorbed into the blood. This includes water in the food and drink, plus water in all the secretions that have been added during digestion. This amounts to between 5–10 dm^3 of water absorbed every day. Another 0.3–0.5 dm^3 of water is absorbed as the remaining gut contents pass through the large intestine. The relatively dry faeces that pass into the rectum are egested through the anus.

EXTENDED

Structure of villi

The intestine is over 6 m long in an adult human, but to increase the rate of transport of food molecules across the small intestine wall, its surface area is increased by millions of finger-like projections called villi (singular: **villus**). The surface area of the cells lining the villi is increased even further by tiny **microvilli**. The combination of all these factors means that the surface area for absorption in the small intestine of an adult human is about 250 m^2, about the size of a tennis court.


small intestine – 6 metres long
there are 20–40 villi per mm^2
blood capillary
lacteal

Δ Fig. 6.13 The structure of the small intestine.

The villi have other adaptations that help to increase the rate of diffusion.

- They are covered in a thin layer of cells, so that digested food molecules do not have to travel far to be absorbed into the blood in the capillaries in the villi.
- They are well supplied with blood capillaries, taking absorbed food molecules from the small intestine to the rest of the body and supplying fresh blood – this keeps the concentration gradient between the digested food in the intestine and the cells in the body as high as possible.
- Villi also contain **lacteals** (part of the **lymphatic system**), which carry fat droplets separately from the rest of the food molecules, because fat does not dissolve well in blood.

END OF EXTENDED

QUESTIONS

1. Define *absorption*.
2. Where in the alimentary canal does absorption of water take place?
3. **EXTENDED** Explain why a large surface area is needed in the small intestine.
4. **EXTENDED** Describe how villi maximise the surface area of the small intestine wall.
5. **EXTENDED** Describe the role of capillaries and the lacteal in a villus.

End of topic checklist

Key words

absorption, alimentary canal, amylase, assimilation, balanced diet, bile, canine, carbohydrate, chemical digestion, constipation, digestion, digestive enzyme, egestion, enamel, enzyme, faeces, fat, fibre, incisor, ingestion, kwashiorkor, lacteal, lipase, malnutrition, marasmus, mechanical digestion, microvilli, mineral, molar, obesity, peristalsis, premolar, protease, protein, soluble, starvation, villus

During your study of this topic you should have learned:

○ How to describe the roles of the main components of a healthy human diet: carbohydrates, proteins, lipids, vitamins (e.g. C and D), minerals (e.g. calcium and iron), water and dietary fibre.

○ That a balanced diet includes all the components needed for health in the right proportions.

○ **EXTENDED** How to explain the causes and effects of malnutrition.

○ **EXTENDED** That diet provides energy, as well as nutrients, and different groups of people have different requirements.

○ That the human alimentary canal is made up of the mouth, salivary glands, oesophagus, stomach, small intestine, pancreas, liver, gall bladder, large intestine and anus.

○ That ingestion takes place in the mouth, digestion is the breakdown of large food molecules into smaller ones by mechanical and chemical digestion, absorption is the taking into the body of nutrients from the small intestine, and egestion is the removal of waste food from the body.

○ How to define assimilation as the movement of digested food molecules into cells.

○ To describe the different types of teeth, including their structures and different functions.

○ That teeth can be cared for by diet and by proper brushing.

○ That chemical digestion breaks down large food molecules into small molecules that can be absorbed.

○ **EXTENDED** To state the functions of digestive enzymes including amylase (digests starch to simpler sugars), lipases (digest fats to fatty acids and glycerol) and proteases (digest proteins to amino acids).

○ That amylase is secreted in the mouth and by the pancreas; lipases are secreted by the pancreas; proteases are secreted in the stomach and by the pancreas: enzymes secreted by the pancreas pass into the small intestine.

○ **EXTENDED** That bile from the liver, stored in the gall bladder until needed, is added to the small intestine to neutralise the acid from the stomach and emulsify fats.

○ **EXTENDED** How to explain that hydrochloric acid in the stomach denatures the enzymes of harmful microorganisms and provides the right pH for gastric enzymes.

○ To state that digested food molecules are absorbed in the small intestine.

○ **EXTENDED** To explain the importance of the villi and microvilli on the surface of the small intestine in providing an enormous surface area for absorption of digested food molecules into blood capillaries and lacteals.

End of topic questions

Note: The marks given for these questions indicate the level of detail required in the answers. In the examination, the number of marks given to questions like these may be different.

1. Describe the importance of the following in a healthy diet:

a) vitamins C and D **(2 marks)**

b) the minerals calcium and iron **(2 marks)**

c) water **(1 mark)**

d) dietary fibre. **(2 marks)**

2. There is an old saying that you should chew your food 100 times before swallowing to help look after your stomach. Explain why chewing food well helps digestion. **(3 marks)**

3. Identify the organs of the digestive system involved, and their role, in each of the following processes:

a) ingestion **(2 marks)**

b) digestion **(5 marks)**

c) absorption. **(2 marks)**

4. This is the diet schedule for a male Olympic athlete training for a competition, not including drinks during training.

breakfast	large bowl of cereal, such as porridge or muesli half pint semi-skimmed milk plus chopped banana 1–2 thick slices wholegrain bread with olive oil or sunflower spread and honey or jam glass of fruit juice + 1 litre fruit squash
post-training 2nd breakfast	portion of scrambled eggs portion of baked beans 1–2 pieces of grilled tofu portion of grilled mushrooms or tomatoes 2 thick slices wholegrain bread with olive oil spread 1 litre fruit squash
lunch	pasta with Bolognese or chicken and mushroom sauce mixed side salad fruit 1 litre fruit squash

post-training snack	4 slices toast with olive oil or sunflower spread and jam large glass of semi-skimmed milk fruit 500 ml water
dinner	grilled lean meat or fish 6–7 boiled new potatoes, large sweet potato or boiled rice large portion of vegetables, e.g. broccoli, carrots, corn or peas 1 bagel 1 low-fat yoghurt and 1 banana or other fruit 750 ml water and squash
bedtime snack	low-fat hot chocolate with 1 cereal bar

a) Identify the foods that contribute to each of these food types:

i) carbohydrates **(5 marks)**

ii) proteins **(3 marks)**

iii) lipids **(2 marks)**

iv) vitamins and minerals **(2 marks)**

v) dietary fibre. **(1 mark)**

b) Which food type is most represented in this diet? **(1 mark)**

c) Explain why this food type is so important in this diet. **(1 mark)**

d) **EXTENDED** Which food group would you expect to be more represented in an athlete's diet in the early stages of training? Explain your answer. **(2 marks)**

e) **EXTENDED** Explain why this diet is not suitable for everyone. **(2 marks)**

Transport is essential to plants and animals; both need oxygen and nutrients to reach their cells for cell respiration. Humans have a specially adapted transport system, including the heart and all of the blood vessels. An average-sized human adult carries about 4.5–5.0 litres of blood. Blood is pumped around the bodies of mammals by the heart to carry oxygen, nutrients and water to every organ, tissue and cell, and to transport waste products away from cells.

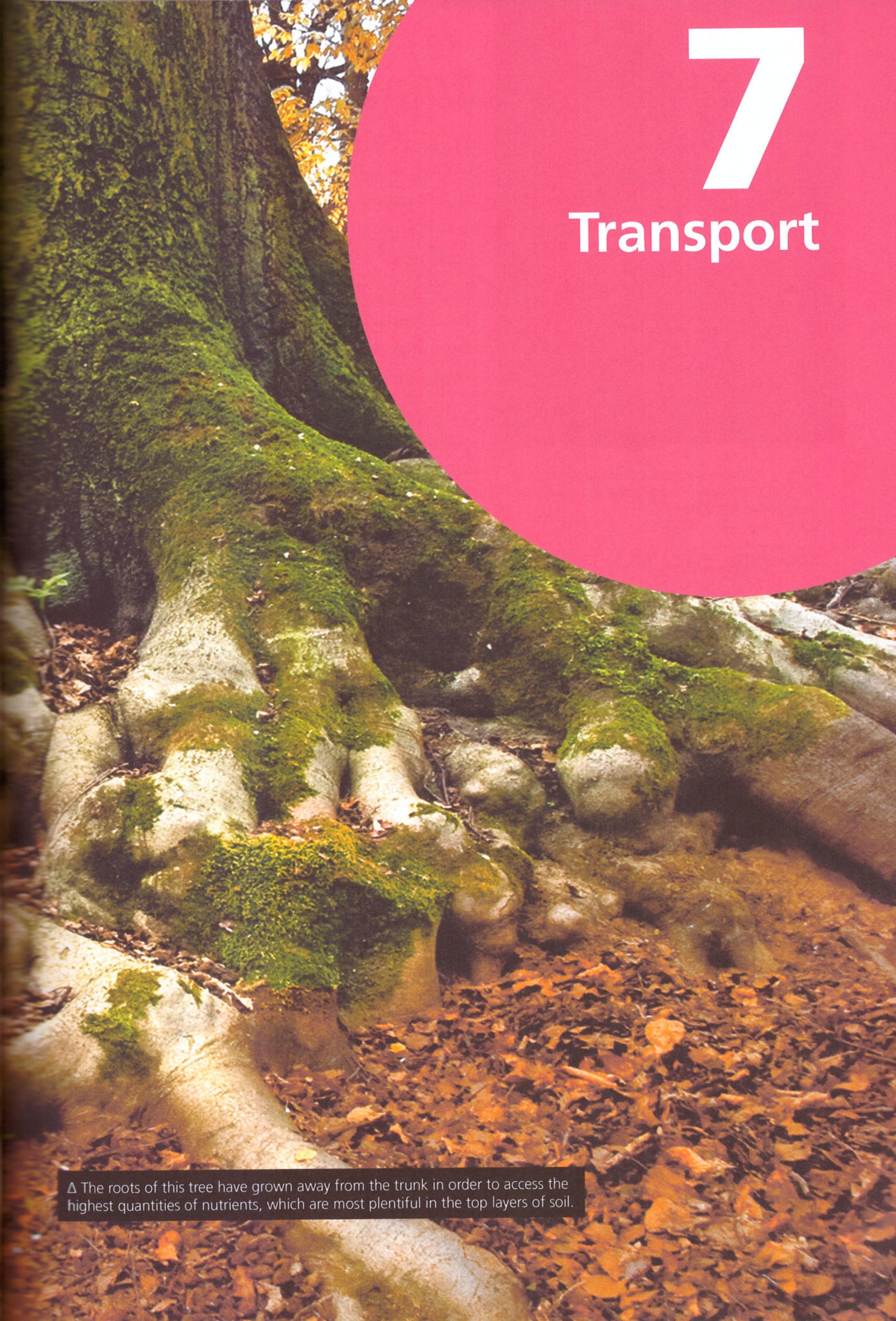
Plants are also dependent on water transport for strength and for photosynthesis. Plants live in many different environments on Earth, from the hot, humid rainforests, to the high, cold mountains. Just like animals, plants need to be well adapted to the conditions in which they live to enable them to survive. In deserts, where water is limited, the air temperature may range from above 40 °C in the day to below zero at night. Plants that survive in the desert have developed special adaptations that allow them to store water, reduce the loss of water from their leaves, and even help to insulate them against the very cold desert nights.

CONTENTS

a) **Transport in plants**
b) Xylem and phloem
c) Water uptake
d) Transpiration
e) Translocation
f) **Transport in mammals**
g) Circulation in mammals
h) The heart
i) Blood vessels
j) Blood

7

Transport



Δ The roots of this tree have grown away from the trunk in order to access the highest quantities of nutrients, which are most plentiful in the top layers of soil.

Δ Fig. 7.1 These fine clouds over the Amazon rainforest are formed from water transpired by trees earlier in the day.

Transport in plants

INTRODUCTION

In one day, hundreds of litres of water will be absorbed from the soil and transpired through a fully grown tree in the Amazonian rainforest. This has a major impact on the environment in the rainforests. It reduces the amount of water in the soil. It also cools the air around the trees as the water evaporates into the air. The increase in water vapour in the air also affects where rainfall occurs. So the trees are effectively controlling the climate.

KNOWLEDGE CHECK

- ✓ Cells in a plant leaf make glucose by photosynthesis, which is converted to sucrose and transported to other parts of the plant in phloem cells.
- ✓ Xylem vessels transport water and mineral ions from the roots of a plant through the stem to the leaves.

LEARNING OBJECTIVES

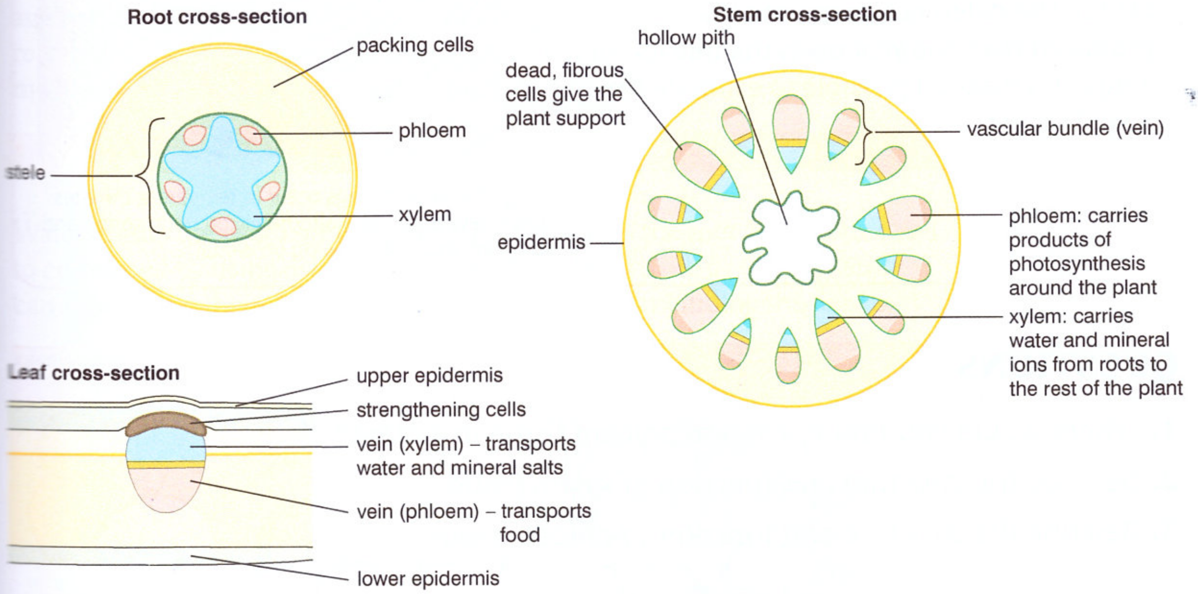
- ✓ State the functions of xylem and be able to identify its position in sections of roots, stems and leaves.
- ✓ State the functions of phloem tissue and identify phloem in sections of plant structures.
- ✓ Identify root hair cells and state their functions.
- ✓ Describe and investigate the pathway taken by water through a plant.
- ✓ **EXTENDED** Explain the importance of the large surface area of root hairs.
- ✓ State that water is transported from the roots to leaves through the xylem vessels.
- ✓ Define the term *transpiration*.
- ✓ Describe and investigate the effect of variation in temperature and humidity on transpiration rate.
- ✓ **EXTENDED** Explain the effects of variation of temperature and humidity on transpiration rate.
- ✓ **EXTENDED** Explain the mechanism by which water moves upwards in the xylem in terms of a transpiration pull, helping to create a water potential gradient that draws up a column of water molecules, held together by cohesion.
- ✓ **EXTENDED** Describe the translocation of sucrose and amino acids in a plant.

XYLEM AND PHLOEM

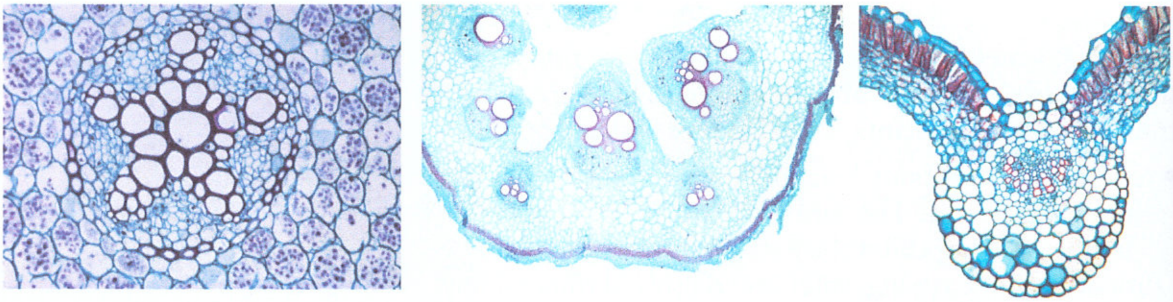
In plants, water and dissolved substances are transported throughout the plant in a series of tubes or vessels. There are two types of transport vessel in plants, called **xylem** and **phloem**.

- Xylem tissue contains long, hollow xylem cells that form long tubes through the plant. The tubes are the hollow remains of dead cells. The thick strong cell walls help to support the plant. Xylem tubes are important for carrying water and dissolved mineral ions, which have entered the plant through the roots, to all the parts of the plant that need them. They are particularly important for supplying the water that the leaf cells need for photosynthesis.
- Phloem cells are living cells that are linked together to form continuous phloem tissue. Dissolved food materials, particularly sucrose and amino acids that have been formed in the leaf, are transported all over the plant from the leaves. For example, sucrose will be carried to any cell that needs glucose for respiration. Sucrose is less reactive than glucose and, therefore, is easier to transport without causing problems for other cells. Sucrose may also be carried to parts of the plants where it will be stored, often as another carbohydrate, such as starch which is stored in seeds and root tubers. This transport of sucrose and other materials is called **translocation**.

In roots the xylem and phloem vessels are usually found separately, but in the stem and leaves they are grouped together as **vascular bundles** or **veins**.


Root cross-section
packing cells
phloem
stele
xylem
Stem cross-section
hollow pith
dead, fibrous cells give the plant support
vascular bundle (vein)
epidermis
phloem: carries products of photosynthesis around the plant
xylem: carries water and mineral ions from roots to the rest of the plant
Leaf cross-section
upper epidermis
strengthening cells
vein (xylem) – transports water and mineral salts
vein (phloem) – transports food
lower epidermis

▲ Fig. 7.2 The positions of xylem and phloem tissue in a root, stem and leaf.



Δ Fig. 7.3 Photomicrographs of (left) a cross-section of the middle of a buttercup root, (middle) a cross-section of part of a pumpkin stem, (right) a cross-section of a vein in a meadow-beauty leaf.

SCIENCE IN CONTEXT

TREE RINGS

The wood of a tree is mostly xylem tissue. Every year, new xylem cells are produced from a ring of cells just inside the bark of the tree. When the tree is growing rapidly, the new xylem cells are large. In temperate regions, such as the UK, the rate of growth and the size of new cells decrease as autumn approaches, and growth stops during winter. The difference in size of cells produced over one year gives the tree its 'rings' and makes it possible to estimate the age of the tree.

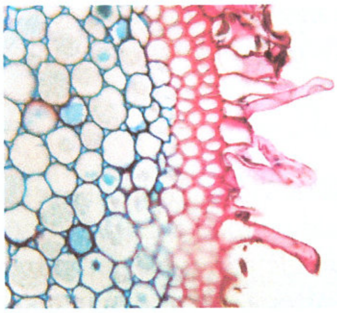
Δ Fig. 7.4 Growth rings occur in temperate climates when new xylem cells alternately grow (in spring and summer) and stop growing (in winter).

QUESTIONS

1. Where would you find xylem and phloem tissue in a plant?
2. Describe the structure and function of xylem tissue.
3. Describe the structure and function of phloem tissue.

WATER UPTAKE

Plants absorb water and dissolved mineral ions from the soil through **root hair cells**. Root hair cells are found in a short region just behind the growing tip of every root. They are very delicate, and easily damaged. As the root grows, the hairs of the cells are lost, and new root hair cells are produced near the tip of the root.



Δ Fig. 7.5 The root of this germinating seed has many fine root hair cells that greatly increase its surface area.

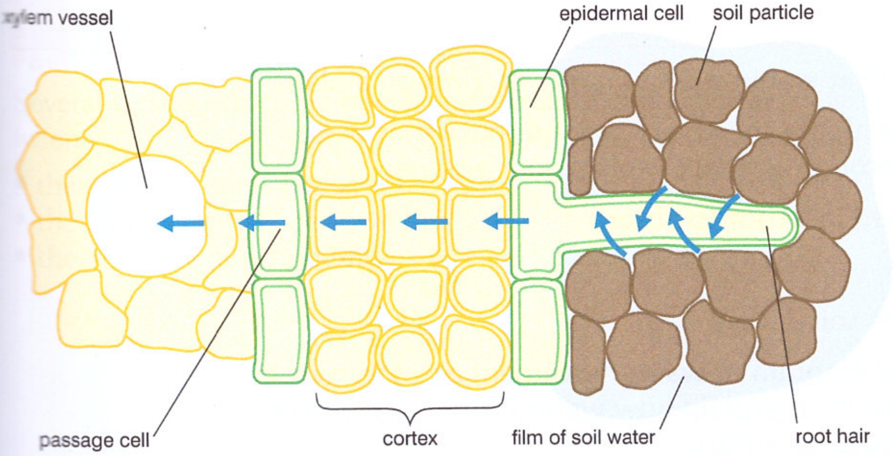
EXTENDED

Root hair cells are specially adapted for absorption of substances, because they have a fine extension that sticks out into the soil. This greatly increases their surface area for absorption. Water enters the root hair cell by **osmosis**, because the concentration of water molecules is higher outside the root, in the soil water, than inside the cytoplasm of the root hair cells. This means that the **water potential** outside the root is higher than inside, so water molecules move down their **water potential gradient**.

Soil water contains minute amounts of dissolved mineral ions. So dissolved mineral ions are usually in higher concentration inside root cells than in the soil water. This means that essential mineral ions cannot usually enter the root by **diffusion**, because that would be against their concentration gradient. Instead, the cell membranes of root hair cells are adapted to take in mineral ions, such as nitrates and magnesium ions, by **active transport**.

END OF EXTENDED

Water enters the root hair cells, then passes across the root from cortex cell to cortex cell by osmosis. It then enters the xylem tissue in the root and can move from there to all other parts of the plant, including the leaves.

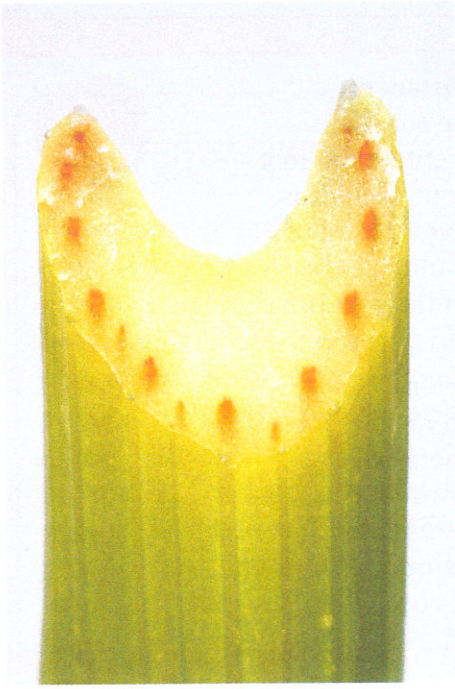


Δ Fig. 7.6 The passage of water across a root.

In the leaves, water moves out of the xylem cells in the vascular bundle, into the cells of the spongy mesophyll by osmosis.

Investigating water movement through a plant

The movement of water through the above-ground parts of a plant can be investigated by adding food colouring to the water given to the plant. Food colouring is soluble and is carried through the plant with the water in the xylem. After a day or two in coloured water, the veins of the leaves and flowers of a plant will show the colour.



Δ Fig. 7.7 A section across a celery stalk that has been standing in coloured water for a day will show colour mainly within the veins (vascular bundles) of the stalk.

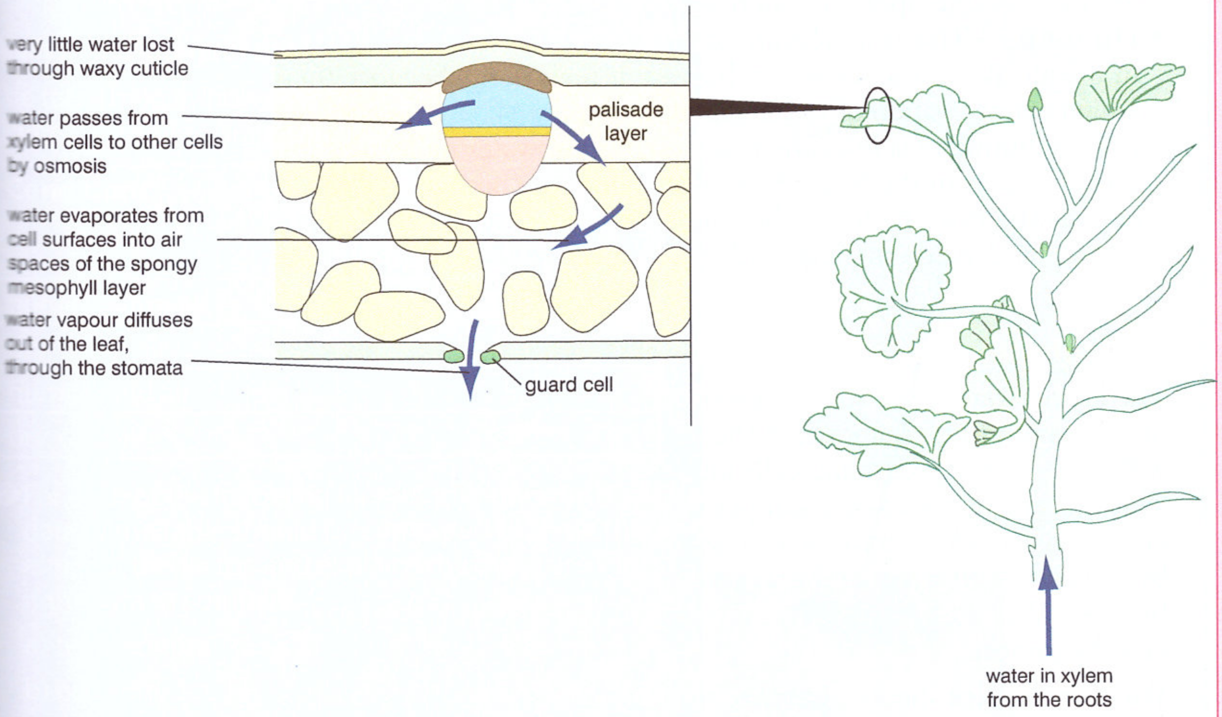
Δ Fig. 7.8 A carnation flower that has been standing in coloured water shows the colour in its petals.

QUESTIONS

1. Describe the route that water takes as it moves through a plant.
2. How could you investigate the above-ground route that water takes as it moves through a plant? Explain your answer.
3. Which process is used in a root to absorb
   - a) water
   - b) mineral ions from soil water?
4. **EXTENDED** Copy the diagram of water movement across a root in Fig. 7.6 and annotate it to explain how water potential controls the movement of water in a root.

TRANSPIRATION

Water is a small molecule that easily crosses cell membranes. Inside the leaf, water molecules cross the cell membranes of the spongy mesophyll cells into the air spaces. This process is called **evaporation** because the liquid water in the cells becomes water vapour in the air spaces. Whenever the **stomata** in a leaf are open, water vapour molecules diffuse from the air spaces out into the air (where there are usually fewer water molecules). So, in addition to using water in the process of photosynthesis, plants lose water vapour by evaporation from the leaf. This loss of water vapour from the leaves is called **transpiration**.


very little water lost through waxy cuticle
water passes from xylem cells to other cells by osmosis
palisade layer
water evaporates from cell surfaces into air spaces of the spongy mesophyll layer
water vapour diffuses out of the leaf, through the stomata
guard cell
water in xylem from the roots

Δ Fig. 7.9 Transpiration in a plant.

Factors that affect the rate of transpiration

Several factors affect the rate of transpiration. Transpiration is faster when:

- the temperature is higher
- the air is moving faster (windier)
- the air is dry (low humidity).

EXTENDED

The rate of transpiration from a leaf will be affected by anything that changes the concentration gradient of water molecules between the leaf and the air. The steeper the concentration gradient, the faster the rate of transpiration.

Several factors can affect the rate of transpiration, including temperature and humidity.

- **Temperature** – Increased temperature means particles have more energy, which results in faster movement of the particles. The faster particles move, the easier it is for them to evaporate from cell surfaces into the air spaces, diffuse out of the leaf and move away. So, increased temperature increases the rate of transpiration.
- **Humidity** – This is a measure of the concentration of water vapour in the air. When the air is very **humid**, it feels damp because there is a high concentration of water vapour in the air. When the air feels dry, the humidity is low. The concentration of water molecules inside the air spaces in the leaf is high. The higher the humidity of the air outside the leaf, the lower the concentration gradient between the air outside and inside the leaf, and so the lower the rate of transpiration.

Transpiration and water potential

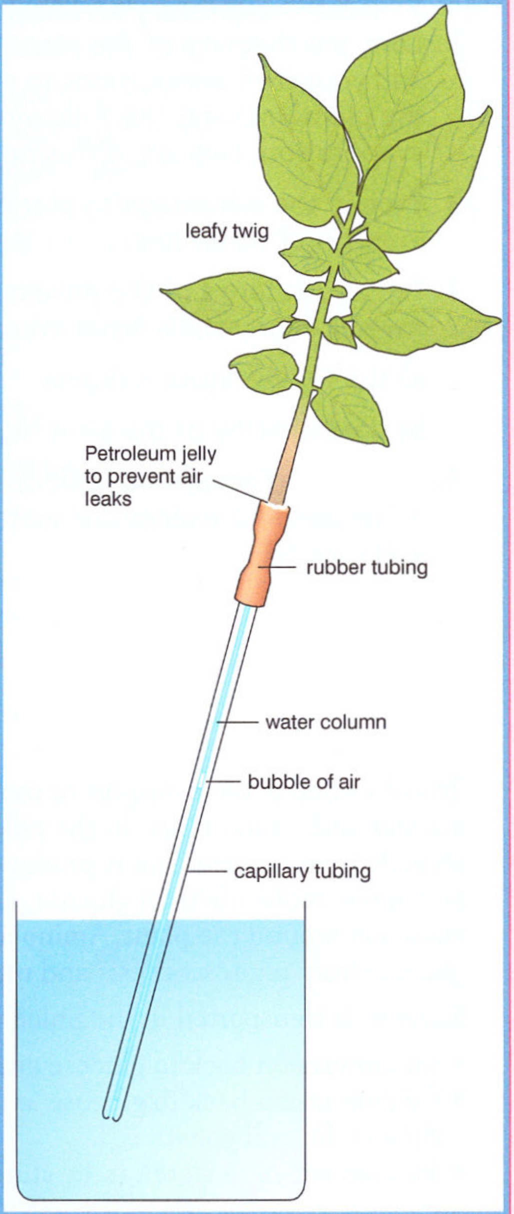
The loss of water from spongy mesophyll cells to the air spaces in a leaf increases the water potential of the cell cytoplasm. So, water molecules will move from surrounding cells into these mesophyll cells by osmosis. This movement creates a water potential gradient between those cells and the ones further into the leaf, so water molecules move into them by osmosis, and so on, all the way back to the xylem in the vascular bundles. Water molecules will move out of the xylem into surrounding cells by osmosis.

Water molecules show **cohesion**, meaning that they have a tendency to stick together. So, as water molecules move out of the xylem cells in a leaf vascular bundle, they create a **tension** (or 'pull') at the top of a xylem tube that connects all the way through the plant to a root (rather like when you suck on a straw). This tension pulls water molecules up the xylem into the leaf, which pulls water molecules out of the root cortical cells into root xylem tubes. The water potential gradient is continued through the root cortical cells to the root hair cells and into the soil water.

END OF EXTENDED

Developing investigative skills

The diagram shows apparatus called a potometer that can be used to investigate the effect of a range of factors on the rate of transpiration. As water evaporates from the leaf surface, the bubble of air in the potometer moves nearer to the leafy twig.



Δ Fig. 7.10 A potometer.

Devise and plan investigations

➊ Suggest how you could use a potometer to measure the effect of the following factors on transpiration: (a) temperature, (b) humidity.

Analyse and interpret data

The table below shows the results of an investigation, using a potometer in four different sets of conditions.

Conditions	Time for water bubble to move 5 cm, in seconds
humid, warm air	135
dry, warm air	75
humid, cold air	257
dry, cold air	122

➋ For each of the following factors, identify which data in the table should be compared to show the effect of the factor, and explain why those are the right data to compare.

a) temperature

b) humidity

➌ Using the data you have identified, draw a conclusion about the effect of the following on the rate of transpiration.

a) temperature

b) humidity

Evaluate data and methods

➍ Explain why the time taken for the bubble to move 5 cm is a measure of transpiration.

➎ What else could make the bubble move?

➏ Explain how could you improve the reliability of the conclusions you drew in Question 3.

QUESTIONS

1. Define the word *transpiration*.
2. Copy the diagram of the plant and leaf section in Fig. 7.9 and add your own annotations to explain how water moves through the plant. Includes the following words in your labels: evaporation, osmosis, diffusion, transpiration.
3. Explain the advantage to plants of closing their stomata at night in terms of water loss.
4. Explain, in terms of the movement of water molecules, why transpiration rate is faster when:
    a) the temperature is higher
    b) the humidity of the air is higher.
5. EXTENDED Explain the relationship between cohesion of water molecules and a continual water potential gradient between leaf and root cells.

EXTENDED

TRANSLOCATION

Translocation is the transport or movement of materials, including sucrose and amino acids, in the phloem of a plant. Sucrose is made directly from glucose that is produced in photosynthesis. Sucrose is a less active molecule than glucose, and so is more straightforward to transport around the plant. Amino acids are produced by cells using glucose from photosynthesis and nitrogen ions taken from the soil.

Sucrose is transported in the phloem to other parts of the plant:

- for conversion back to glucose and use in respiration
- for conversion back to glucose and production of other molecules in the cell for cell growth
- for conversion to starch to be stored until needed.

Amino acids are used to produce proteins for the formation of new plant tissue during growth, and to produce enzymes needed to control cell reactions.

Sources and sinks

We can describe translocation in terms of sources and sinks.

- A **source** is where a substance is produced or is supplied to the plant.
- A **sink** is where the substance is used or converted to another substance.

In translocation, the *source* of glucose is the photosynthesising cells of the leaf. The main *sinks* for glucose are the root and shoot tips, and the flowers. Some plants may also direct glucose to storage organs, such as root and stem tubers (e.g. potato), where it is converted to starch that can be used at the start of the next growing season for rapid new growth.

QUESTIONS

1. In which tissue does translocation occur in a plant?

2. Give two examples of substances that are translocated.

END OF EXTENDED

End of topic checklist

Key words

active transport, cohesion, diffusion, evaporation, humidity, osmosis, phloem, root hair cell, stomata, tension, translocation, transpiration, vascular bundle, water potential gradient, xylem

During your study of this topic you should have learned:

○ That xylem tissue transports water and mineral ions from plant roots to other parts of the plant.

○ That phloem tissue carries sucrose and amino acids from where they are made in the leaves to other parts of the plant.

○ That root hair cells are the site of absorption of water and mineral ions into a plant.

○ **EXTENDED** How to explain the importance of the large surface area of root hair cells.

○ To explain how water is absorbed from the soil through root hair cells and crosses the root cells to the xylem. It then passes up the stem in the xylem to the leaf and moves through the spongy mesophyll cells to the air spaces.

○ To explain that transpiration is the evaporation of water from the surfaces of a plant, mostly through the stomata.

○ To explain that the rate of transpiration increases with increased temperature and decreased humidity.

○ **EXTENDED** To describe the roles of osmosis and active transport in the uptake of water and ions by a plant.

○ **EXTENDED** That the transpiration of water from the leaf causes a water potential gradient to be set up through the plant, across the leaf and through the xylem in the stem to the root, and cohesion of water molecules is important in this.

○ **EXTENDED** To define translocation as the transport of substances such as sucrose and amino acids from the cells in which they are made, through the phloem to the parts of the plant where they are used to produce energy or other molecules for growth or are stored for later use.

○ **EXTENDED** That the *source* of a substance in a plant is where it was made or entered the plant; the *sink* is where the substance is used or exits the plant.

End of topic questions

Note: The marks given for these questions indicate the level of detail required in the answers. In the examination, the number of marks given to questions like these may be different.

1. Look at the photos in Fig. 7.3 of sections through a plant leaf, stem and root.

a) Using a sharp pencil, make careful diagrams that show the positions of all the main tissues in the sections. (Only draw a few cells in each tissue, to show their form. It will take too long to draw all the cells.) **(3 marks)**

b) Use the labelled diagrams in Fig. 7.2 to help you to clearly label your drawings to show the position of xylem in each location. **(3 marks)**

c) Clearly label the position of phloem in each of your drawings. **(3 marks)**

2. Flower sellers sometimes produce flowers of unusual colours for sale, starting with white flowers. Explain how they may do this, and why it is possible. **(4 marks)**

3. **EXTENDED** Cactus plants have many adaptations to help them survive in a dry desert. One of these adaptations is that they close their stomata during the day and open them at night. Explain fully the advantage of this adaptation. **(4 marks)**

4. **EXTENDED** Explain how and why different parts of a plant are sinks for the translocation of sucrose at different times of the year in a country where there are seasons, such as Russia. **(7 marks)**

Δ Fig. 7.11 This photograph shows the airways, bronchi and bronchioles that are found in a lung. The millions of capillaries are not visible.

Transport in mammals

INTRODUCTION

Almost no cell in your body is more than 20 μm (0.02 mm) from a blood vessel. This is because the blood delivers a constant supply of oxygen and glucose, for respiration, without which the cells will rapidly die. So it's not surprising that, no matter where you cut yourself, you will bleed. Many of the blood vessels that penetrate the tissues are extremely narrow – about 5 to10 μm wide, which is about the width of one red blood cell. It has been calculated that, if you placed the blood vessels of an adult in a line, it would wrap four times around the equator of the Earth.

KNOWLEDGE CHECK

- ✓ The heart and blood vessels form the human circulatory system.
- ✓ Cells need a continuous supply of oxygen and glucose for respiration, which are supplied by the blood in a human body.

LEARNING OBJECTIVES

- ✓ Describe the circulatory system as a system of continuous blood vessels, with a pump and valves to ensure one-way flow of blood.
- ✓ **EXTENDED** Describe the double circulation in terms of circulation to the lungs and circulation to the body tissues in mammals.
- ✓ **EXTENDED** Explain the advantages of a double circulation.
- ✓ State that blood is pumped away from the heart into arteries and returns to the heart in veins.
- ✓ Name the main blood vessels to and from the heart, to and from the lungs, and to and from the kidneys.
- ✓ Name and identify the structures of the mammalian heart.
- ✓ **EXTENDED** Explain how the structure of the heart is linked to its function.
- ✓ Investigate and state the effect of exercise on pulse rate.
- ✓ **EXTENDED** Explain the effect of physical activity on the heart rate.
- ✓ **EXTENDED** Describe coronary heart disease and state the possible risk factors.
- ✓ Describe the structure of arteries, veins and capillaries.
- ✓ **EXTENDED** Explain how the structure of different blood vessels is related to their different roles in transporting blood.
- ✓ List the main components of human blood, and describe their functions.
- ✓ Identify red and white blood cells in diagrams, light microscope slides and photomicrographs.

CIRCULATION IN MAMMALS

Transport in animals usually takes place inside a **circulatory system**. A circulatory system is formed from a system of continuous tubes (blood vessels) that carry blood around the body. The tubes are connected to a pump, the heart, which forces the blood through the circulation. Valves in the heart and in some of the blood vessels make sure that blood circulates in only one direction.

EXTENDED

Different circulatory systems

The mammalian circulatory system (as in humans) is described as a **double circulation** because the blood passes through the heart twice for each time that it passes through the body tissues. This is because when blood leaves the left side of the heart it passes through the tissues of the lungs, before returning to the heart for pumping around the rest of the body.

Separating the circulation to the lungs from the circulation to the body means that the blood in the two circulations can be at different pressures.

- Blood leaving the left side of the heart is normally below 4 kPa. Blood does not travel far to the lung tissue, so there is little loss of pressure before it reaches the capillaries surrounding the alveoli. This lower pressure prevents damage to the delicate capillaries that pass through lung tissue.
- Blood leaving the right side of the heart has to travel all round the body and back to the heart. So it needs to start at a much higher pressure, at about 16 kPa as it leaves the heart. By the time it reaches the capillaries within body tissues, the pressure has dropped to below 3 kPa and so will not damage them.

END OF EXTENDED

QUESTIONS

1. What is the role of the heart in the circulatory system?
2. What prevents blood flowing the wrong way round the circulatory system?
3. EXTENDED Explain what is meant by a *double circulatory system*.
4. EXTENDED Explain the advantages of a double circulatory system.

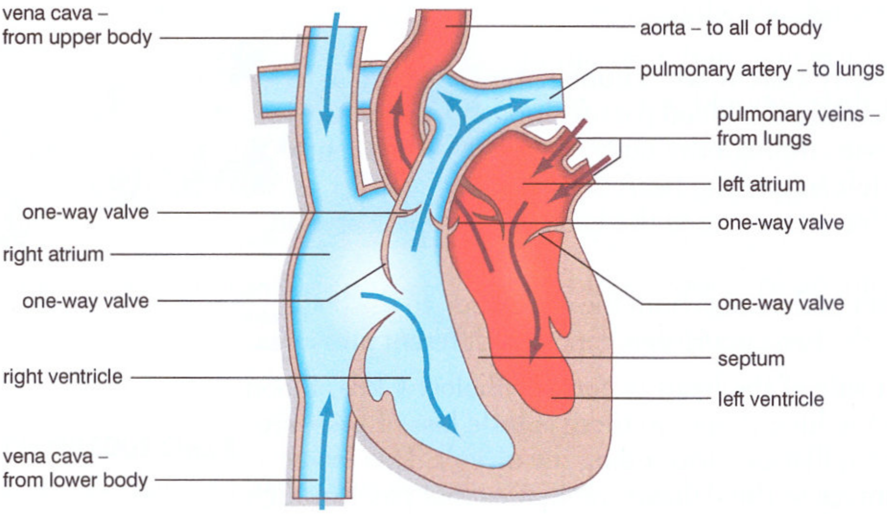
THE HEART

The **heart** is a muscular organ that pumps blood by expanding in size as it fills with blood, and then contracting, forcing the blood on its way through the blood vessels. Blood is pumped away from the heart in arteries and returns to the heart through veins.

EXTENDED

The heart is two pumps in one. The right side and left side are separated by a layer of tissue called the septum. The right side pumps blood to the lungs to collect oxygen. The left side then pumps the **oxygenated** blood around the rest of the body. The **deoxygenated** (without oxygen) blood then returns to the right side, to be sent to the lungs again.

END OF EXTENDED


vena cava – from upper body
aorta – to all of body
pulmonary artery – to lungs
pulmonary veins – from lungs
left atrium
one-way valve
one-way valve
right atrium
one-way valve
one-way valve
septum
right ventricle
left ventricle
vena cava – from lower body

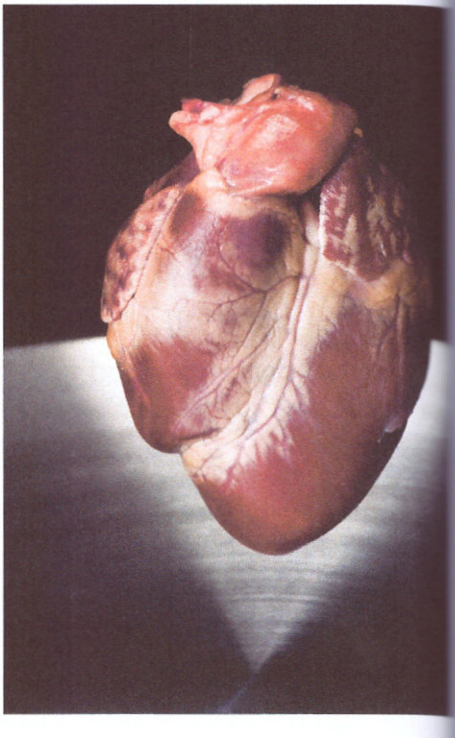
◁ Fig. 7.12 Structure of the human heart. Oxygenated blood is shown in red and deoxygenated blood is shown in blue.

REMEMBER

We always draw diagrams of the circulatory system and heart as if looking in a mirror, or at another person. So in the diagram the 'left' side of the heart/circulation in a body is drawn on the right side of the diagram.

The heart consists of four chambers: two **atria** (single: atrium) and two **ventricles**. The walls of the chambers are formed from thick muscle. Blood that flows toward the heart passes through blood vessels called **veins**. Blood that leaves the heart passes through blood vessels called **arteries.** To make sure that blood only flows in one direction through the heart, there are **valves** at the points where blood vessels enter and leave the heart, and between the atria and ventricles. These close when the heart contracts, to prevent backflow of blood.

The heart has its own separate blood supply, to provide the muscle tissue with oxygen and glucose for respiration so that it can contract. These blood vessels are called the coronary arteries and coronary veins. You can see some of these on the outside of a whole heart.



Δ Fig. 7.13 Whole human heart.

EXTENDED

Blood flow through the heart

Blood passes through the chambers of the heart in a particular sequence as the walls of the chambers contract. First the atria contract at the same time, then the ventricles both contract at the same time, to move the blood through the heart.

- Blood from the body arrives at the heart via the vena cava, and enters the right atrium.
- Contraction of the right atrium passes blood through the one-way valve to the right ventricle.
- Contraction of the right ventricle forces blood out through the pulmonary artery to the lungs. The one-way valve at the entrance to the pulmonary artery closes to prevent backflow of blood into the right atrium, and the one-way valve between the atrium and ventricle then closes to prevent backflow of blood into the ventricle.
- Blood enters the left atrium from the lungs through the pulmonary vein.
- Contraction of the left atrium passes blood to the left ventricle through the one-way valve.
- Contraction of the left ventricle forces blood out through the aorta toward the rest of the body. The one-way valve at the entrance to the aorta closes to prevent backflow of blood into the left atrium, and then the one-way valve between the atrium and ventricle closes to prevent backflow of blood into the ventricle.

END OF EXTENDED

QUESTIONS

1. Name the four chambers of the mammalian heart.
2. Distinguish between *arteries* and *veins*.
3. EXTENDED Starting in the vena cava, list the chambers and blood vessels in the order that blood passes through them until it reaches the aorta.

Heart rate

Heart rate is the measure of how frequently the heart beats, generally given as beats per minute. We can take measurements of heart rate by feeling for a pulse point, where the blood flows through an artery near to the skin, such as in the wrist or at the temple.

Taking the pulse rate is actually measuring the expansion and relaxation of the artery wall as the blood passes through it. However, as each pulse of blood is created by one contraction of the ventricles, we say that we are measuring *heart beats*.

Δ Fig. 7.14 Taking the pulse at the wrist.

Heart rate can also be measured by listening to the heart itself. The 'lub, dup' sounds of one complete contraction are the sounds of the valves inside the heart as they open and shut.

Resting heart rate is the rate at which the heart beats when the person is at rest. On average it is between 60 and 80 beats per minute for an adult human, but this range is very variable. Resting heart rate may vary as a result of:

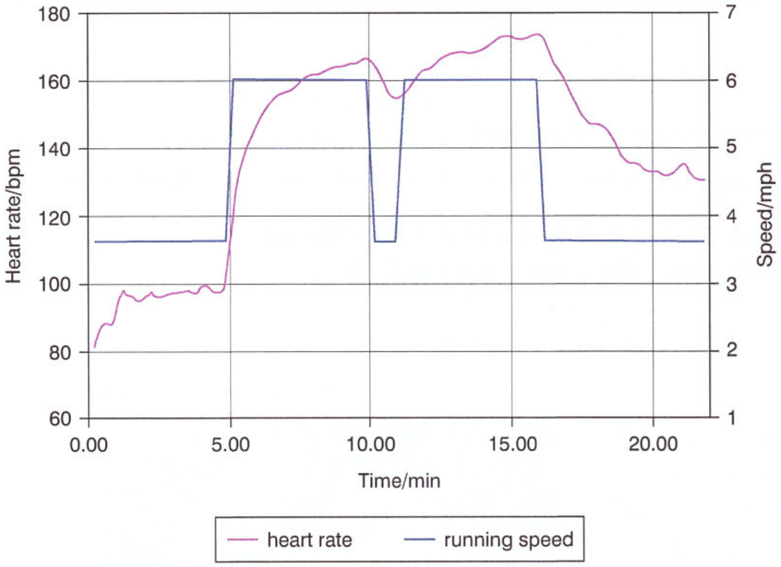
- age – children usually have a faster average than adults
- fitness – a trained athlete may have a resting rate as low as 40 beats per minute because their heart contains more muscle and can pump out more blood with each contraction
- illness – infection can raise resting heart rate, but some diseases of the circulatory system can slow resting heart rate
- drugs – some drugs can change heart rate.

Changing heart rate

Heart rate increases during activity. The harder you exercise, the faster the heart beats.

EXTENDED

The increase in heart rate increases the amount of blood that is pumped around the body, and the speed with which it reaches body tissues. This supplies oxygen and glucose more rapidly to respiring cells, particularly in the muscles, and removes waste products more rapidly.



Δ Fig. 7.15 How heart rate changes with exercise.

END OF EXTENDED

Developing investigative skills

The effect of exercise on heart rate can be measured by taking pulse measurements after different levels of exercise.

Devise and plan investigations

In an investigation of the effect of exercise on the heart rate, a student was asked to exercise at different levels for 2 minutes, at which point the pulse rate was measured. The student was allowed to rest for 5 minutes and then continued to exercise at the next level of activity.

❶ a) Explain why the pulse rate was taken after 2 minutes of exercise and not sooner.

b) Explain why the student rested for 5 minutes before starting the next level of exercise.

Analyse and interpret data

Table 7.1 shows the results of an investigation into the effect of exercise on heart rate of one student.

	Resting	Walking	Jogging	Running
heart rate beats per minute)	72	81	96	122

∆ Table 7.1 Heart rate with activity.

❷ Describe the pattern shown in the data.

❸ Use the data to draw a conclusion for the investigation.

❹ Explain why heart rate responds like this to different levels of exercise.

Evaluate data and methods

❺ How reliable is this conclusion, and what could have been done during the investigation to improve the reliability?

QUESTIONS

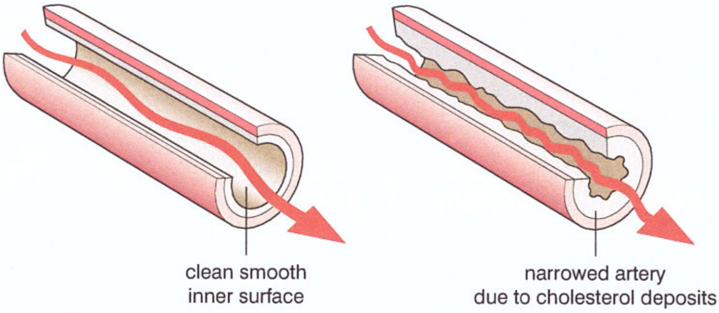
1. Explain why resting heart rate in an adult is given as a range of values and not a single value.
2. Describe the effect of activity on heart rate.
3. EXTENDED Explain the effect of activity on heart rate.

EXTENDED

Coronary heart disease

The muscle of the heart needs its own blood supply to provide oxygen and sugars for respiration. The heart cannot get these materials from the blood that flows through it, so there are coronary arteries and veins passing through heart muscle. If the blood flow through these coronary blood vessels is reduced, it can reduce the amount of oxygen and sugars getting to the muscle cells, and so reduce the amount of energy that they can release through respiration.

Blockage of the coronary arteries can occur when layers of cholesterol are deposited on the inner lining of the blood vessel. This causes **coronary heart disease**. Even partial blockage can cause a health problem, such as angina (heart pains) or high blood pressure. A full blockage will cause a **heart attack**, which may result in death.


clean smooth inner surface
narrowed artery due to cholesterol deposits

Δ Fig. 7.16 Deposits of cholesterol inside arteries make it more difficult for blood to flow through freely, increasing the risk of diseases of the circulatory system.

Some factors can increase the risk of a blockage of the coronary arteries:

- **diet** – high levels of saturated fats in the diet (particularly from red meats) may cause increased deposits of cholesterol
- **smoking** – chemicals in tobacco smoke that pass into the blood can damage the delicate lining of arteries, and cholesterol is more likely to be laid down at these points.

Stress is not a direct cause of coronary heart disease, but response to stress, such as smoking, drinking alcohol or eating for comfort, particularly over a long time, can increase the risk of heart disease.

Genes can give some people a tendency toward developing coronary heart disease. As this tendency can be inherited, the disease may appear more commonly in some families than in others, and more frequently in some particular ethnic groups than others. For example, African-Americans are at greater risk of developing coronary heart disease than white Americans.

END OF EXTENDED

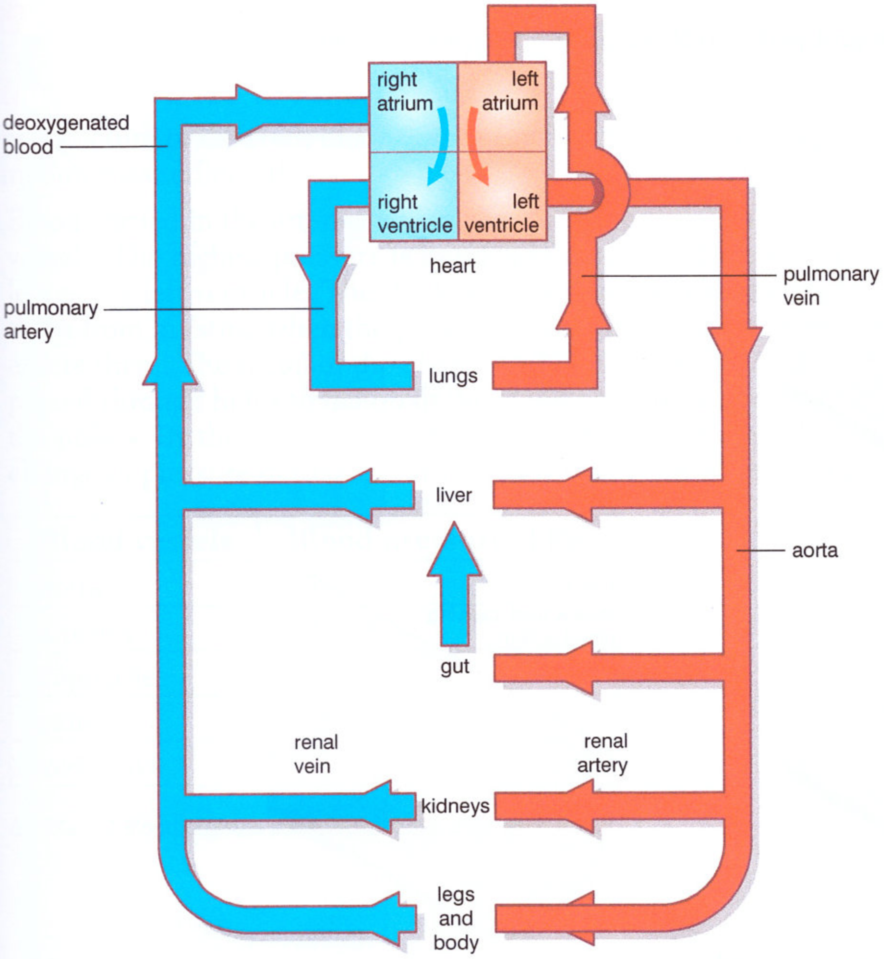
QUESTIONS

1. Explain why the heart needs its own blood supply.
2. EXTENDED Identify four possible risk factors for coronary heart disease.
3. EXTENDED Explain how a person can reduce their risk of coronary heart disease.

BLOOD VESSELS

Circulation

Fig. 7.17 shows a simplified layout of the human circulatory system, including the major blood vessels. The name of a major blood vessel is



right atrium
left atrium
right ventricle
left ventricle
deoxygenated blood
heart
pulmonary artery
pulmonary vein
lungs
liver
aorta
gut
renal vein
renal artery
kidneys
legs and body

Δ Fig. 7.17 Plan of the human circulatory system.

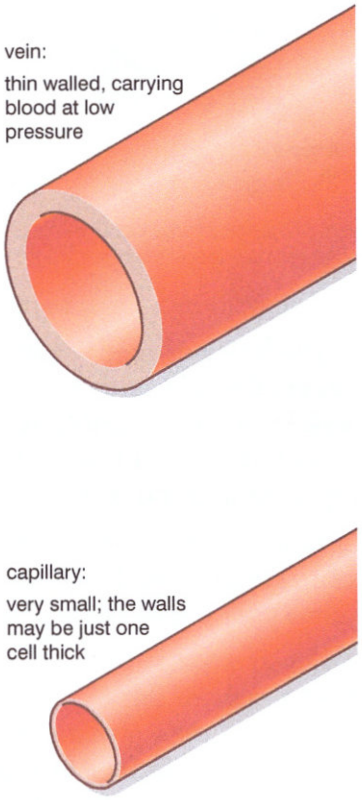
often related to the organ it supplies: *coronary* for heart (from the Latin *corona* for 'crown' because the blood vessels surround the top of the heart like a crown), *renal* for kidneys (from the Latin *renes* meaning 'the kidneys'), *pulmonary* for lungs (from the Latin *pulmonis* meaning 'lungs'). Learn the names of the blood vessels that are associated with the heart, the lungs and kidneys.

The largest vein and the largest artery in the body have special names. The **vena cava** is the vein that carries blood to the heart, and the **aorta** is the artery that receives blood from the heart.

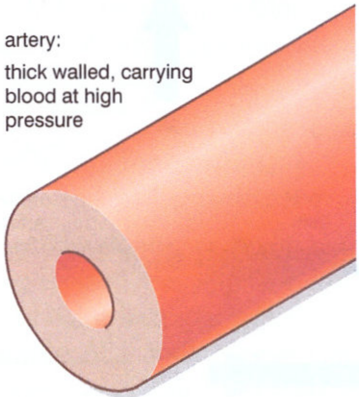
REMEMBER

Remember, **a** for arteries that travel **a**way from the heart. **V**eins carry blood into the heart and contain **v**alves.

The blood vessels are grouped into three different types: arteries, capillaries and veins.


vein:
thin walled, carrying blood at low pressure
capillary:
very small; the walls may be just one cell thick

Δ Fig. 7.18 Veins vary in diameter from about 5 to 15 mm. Capillaries are very small, with a diameter of around 0.01 mm.


artery:
thick walled, carrying blood at high pressure

Δ Fig. 7.19 Arteries vary in diameter from about 10 to 25 mm.

- **Arteries** are large blood vessels that carry blood which is flowing away from the heart. Arteries have thick muscular and elastic walls, with a narrow central space (lumen) through which the blood flows.
- **Capillaries** are the tiny blood vessels that form a network throughout every tissue and connect arteries to veins. Capillaries have very thin walls. All the exchange of substances between the blood and tissues happens in the capillaries.
- **Veins** are large blood vessels that carry blood that is flowing back toward the heart. Veins have a large lumen through which blood flows. Valves in the veins prevent backflow.
- As arteries divide more as they get further from the heart, they get narrower. The narrow vessels that connect arteries to capillaries are called **arterioles**.

EXTENDED

Structure related to function

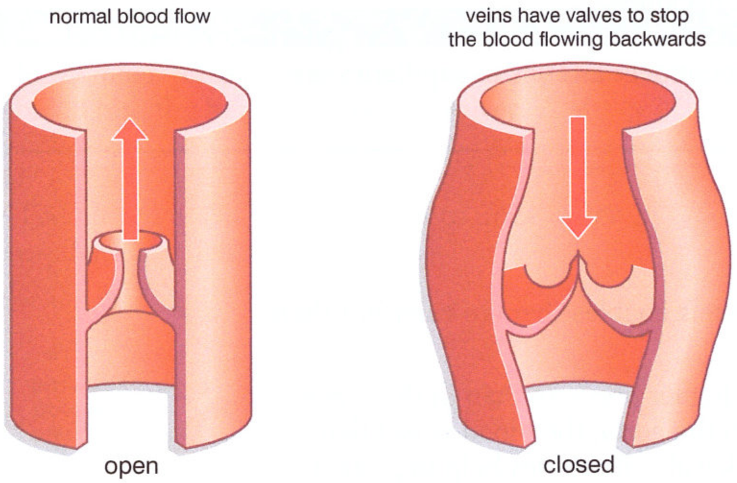
The structure of different blood vessels enables them to carry out their function most efficiently.

- Blood carried in the arteries is at higher pressure than in the other vessels. The highest pressure is in the aorta, the blood vessel that leaves the left ventricle. The thick walls of arteries help to protect them from bursting when the pressure increases as the pulse of blood enters them. The recoil of the elastic wall after the pulse of blood has passed through helps to maintain the blood pressure and even out the pulses. By the time the blood enters the fine capillaries, the change in pressure during and after a pulse has been greatly reduced.

Blood vessels	Blood pressure (kPa)
aorta	>13
arteries	13–5.3
capillaries	3.3–1.6
veins	1.3–0.7
vena cava	0.3

∆ Table 7.2 Blood pressure in different blood vessels.

- The thin walls of capillaries helps to increase the rate of **diffusion** of substances by keeping the distance for diffusion between the blood and cell cytoplasm to a minimum.
- By the time blood leaves the capillaries and enters the veins, there is no pulse and the blood pressure is very low. The large lumen (centre) of the veins allows blood to flow easily back to the heart. The contraction of body muscles, such as in the legs, helps to push the blood back toward the heart against the force of gravity. The valves make sure that blood can flow only in the right direction, back toward the heart.



Δ Fig. 7.20 Valves in the veins make sure that blood can only move in one direction, toward the heart.

END OF EXTENDED

QUESTIONS

1. Name the following blood vessels:
   a) the vessels that carry blood to the kidneys
   b) the vessel that carries blood from the heart toward the body
   c) the vessels that carry blood from the lungs back toward the heart.
2. Describe the differences in structure of arteries, capillaries and veins.
3. **EXTENDED** Explain how the structure of arteries helps to reduce and even out the blood pulses from the heart.

SCIENCE LINK

CHEMISTRY – PARTICLE NATURE OF MATTER

- In liquids, such as the blood, the particles are able to move over each other, which allows blood flow to happen.
- Substances need to move into and out of the bloodstream, so ideas about the relative size of the different particles become important.

PHYSICS – SIMPLE KINETIC THEORY, FORCES

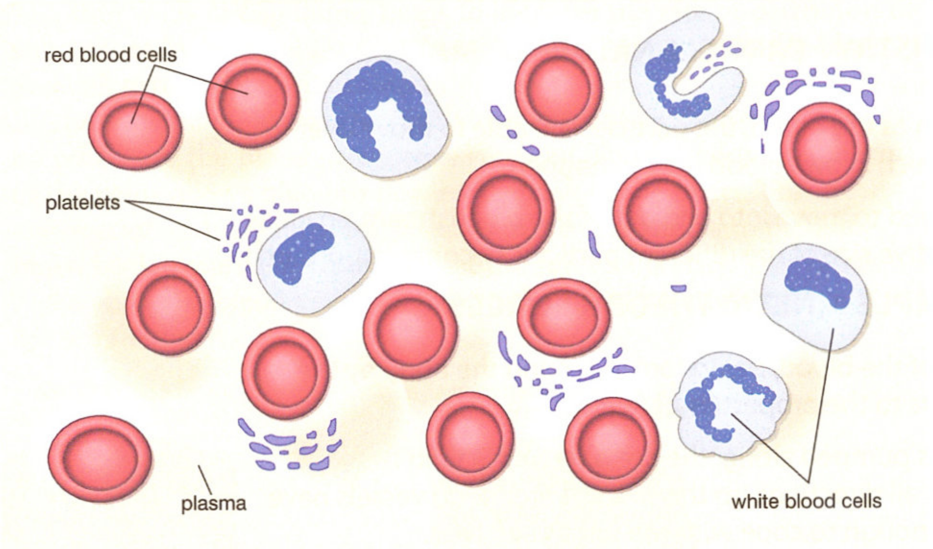
- The pressure of the blood, being forced around the body by the heart, also links to the properties of fluids.
- As the blood is pumped along, the pressure in the fluid is transmitted in all directions, so the sides of the blood vessels have to be strong enough to cope with the forces involved.

BLOOD

The human circulatory system carries substances around the body. The table shows some of the important substances that are transported around the human body. These substances are carried within the blood, in different forms.

Substance	Carried from	Carried to
molecules absorbed from digested food, e.g. glucose, amino acids, fatty acids	small intestine	all parts of the body
water	intestines	all parts of the body
oxygen	lungs	all parts of the body
carbon dioxide	all parts of the body	lungs
urea (waste)	liver	kidneys
hormones	glands	all parts of the body (different hormones affect different parts)

Δ Table 7.3 Substances carried by the blood around the body.



Δ Fig. 7.21 Blood is mostly water, containing cells and many dissolved substances.

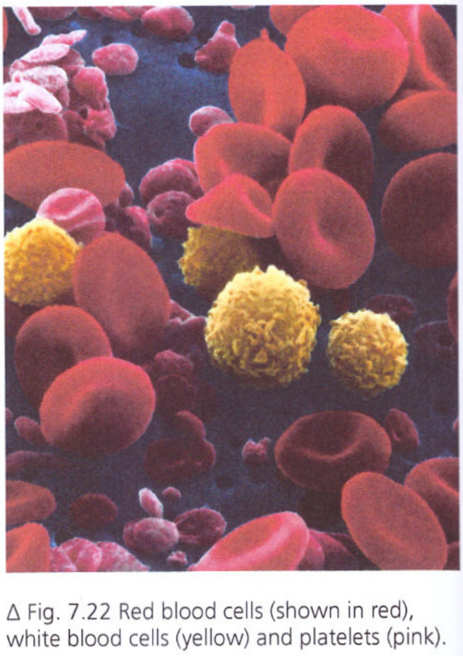
Blood contains plasma, red blood cells, white blood cells and platelets. Each of these has a particular function in the body.

Plasma

Plasma is the straw-coloured, liquid part of blood. It mainly consists of water, which makes it a good solvent for many substances. Digested food molecules, such as glucose and amino acids, easily dissolve in plasma. Urea, which is formed by the liver from excess amino acids, is also soluble in plasma. Many hormones (see Topic 9) are also soluble and are carried around the body dissolved in plasma. Carbon dioxide dissolves in water to form carbonic acid (H_2CO_3), and most carbon dioxide is carried in the blood in this form.

Red blood cells

Red blood cells are the most common cell in the blood. They are a characteristic **biconcave** shape and have no nucleus, this makes them flexible and enables them to carry more **haemoglobin**. Haemoglobin is a protein that transports oxygen, and is what gives the cells their red colour.



Δ Fig. 7.22 Red blood cells (shown in red), white blood cells (yellow) and platelets (pink).

White blood cells

There are several different types of white blood cell, but they all play an important role in defending the body against disease. They are part of the **immune system** that responds to infection by trying to kill the **pathogen** (the disease-causing organism). Some kinds of white blood cell kill pathogens by engulfing (flowing around the pathogen until it is completely enclosed), which is known as **phagocytosis**. Other kinds of white blood cell produce chemicals called **antibodies** that attack pathogens.

Platelets

Platelets are small fragments of much larger cells that are also important in protecting us from infection by causing blood to clot when there is damage to a blood vessel.

SCIENCE IN CONTEXT

BLOOD TESTS

Doctors often send blood off to be tested when a patient is unwell. These tests not only check the concentrations of different substances in the blood, such as glucose, they also count the number of different kinds of cells. Taking a blood sample can be quick and easy for a doctor to do, and the tests can help in diagnosing what is wrong with the patient.

- An abnormal concentration of glucose may indicate diabetes.
- Too few white blood cells may indicate liver or bone marrow disease.
- Too few red blood cells can make the blood look paler than normal. Low numbers of red blood cells cause anaemia, which usually results in the patient feeling very tired.

Any abnormal results are followed up with other tests to confirm diagnosis.

QUESTIONS

1. Draw up a table to show the components of blood and the roles that they play in the body.
2. Explain how the structure of a red blood cell is adapted to its function.
3. Describe the role of white blood cells in the immune system.

End of topic checklist

Key words

aorta, artery, atrium, capillary, circulatory system, coronary heart disease, deoxygenated, double circulation, haemoglobin, heart, heart attack, heart rate, oxygenated, plasma, platelet, red blood cell, valve, vein, vena cava, ventricle

During your study of this topic you should have learned:

○ To describe a circulatory system as consisting of tubes that carry blood around the body, where the blood is pushed by a pump called the heart.

○ **EXTENDED** To describe the double circulatory system of humans in which blood from the right side of the heart is pumped through the lungs, then back to the left side of the heart and to the rest of the body.

○ The heart pumps blood through arteries, then through capillaries, and finally through the veins back to the heart.

○ The heart is formed from four chambers, two atria and two ventricles, which have muscular walls to push blood through the heart. Valves prevent backflow of blood so that it only flows in one direction.

○ **EXTENDED** The heart pumps blood by the contraction of the atria followed by the ventricles, with one-way valves preventing the backflow of blood. The septum separates oxygenated from deoxygenated blood.

○ Heart rate increases during exercise.

○ **EXTENDED** Increase in heart rate during exercise supplies oxygen and glucose more rapidly to active muscle cells and removes carbon dioxide more rapidly.

○ To describe coronary heart disease as caused by the blockage of a coronary artery.

○ Diet, smoking, stress and genetic tendency are all risk factors for coronary heart disease.

○ To describe the structure of arteries including the thick muscular walls and thin central lumen.

○ **EXTENDED** The muscular walls of arteries resist the pressure of blood as it enters and even out the change in pressure as blood flows through.

○ How to describe the structure of veins and capillaries.

End of topic checklist continued

○ **EXTENDED** The thin capillary walls make it easier for substances such as carbon dioxide, oxygen and glucose to be exchanged with cells.

○ **EXTENDED** The large lumen in veins helps blood to flow easily through them, and the valves prevent the blood flowing in the wrong direction.

○ Human blood is formed from liquid plasma that carries red blood cells, white blood cells and platelets around the body.

○ Plasma is mostly water in which many substances dissolve, such as glucose, urea and hormones.

○ **EXTENDED** How to identify red and white blood cells in diagrams and photomicrographs.

○ Red blood cells have a biconcave disc shape, contain large amounts of haemoglobin, and are small and flexible so that they can carry oxygen efficiently to all the cells in the body.

○ White blood cells protect against infection, by the phagocytosis of pathogens and by producing antibodies.

End of topic questions

Note: The marks given for these questions indicate the level of detail required in the answers. In the examination, the number of marks given to questions like these may be different.

1. People who suffer from anaemia often have a low red blood cell count (fewer blood cells per mm^3 blood) than usual. One of the symptoms of anaemia is becoming tired more easily than usual. Explain why this symptom occurs. **(4 marks)**

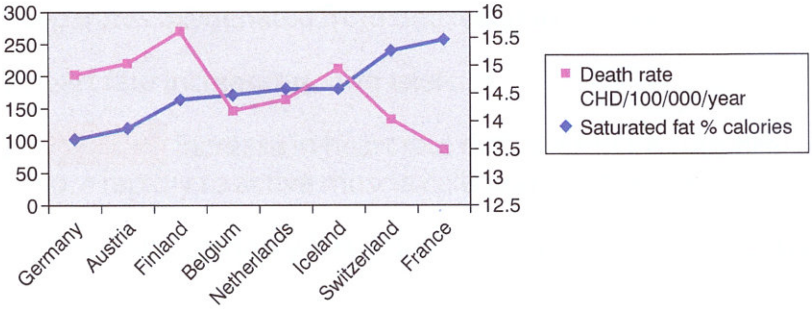
2. Doctors look for risk factors in a person's lifestyle to help advise their patients on how to live more healthily.

   a) EXTENDED Describe how coronary heart disease occurs. **(3 marks)**

   b) EXTENDED Describe four risk factors that can increase the likelihood of developing coronary heart disease. **(4 marks)**

3. EXTENDED The blood pressure of blood leaving the right ventricle of the human heart is 3 kPa, and from the left ventricle is around 16 kPa. Explain how the heart can produce these different pressures, and why this difference is important for the body. **(4 marks)**

4. EXTENDED The graph shows the death rate from coronary heart disease (CHD) in some European countries compared with the proportion of the energy in the average diet in those countries that is provided by saturated fat.



Δ Fig. 7.23 Death rates and saturated fat intake for some European countries.

   a) Saturated fat consumption is a risk factor for coronary heart disease. Explain what we mean by a *risk factor*. **(1 mark)**

   b) Explain why saturated fat consumption is a risk factor for coronary heart disease. **(1 mark)**

   c) Analyse the shape of the graph. **(3 marks)**

   d) Some people think this graph indicates that there is no correlation between saturated fat consumption and CHD. Evaluate this idea. **(4 marks)**

Our lungs are the organs that carry out gas exchange. They allow the body to take in oxygen from the air and expel carbon dioxide that is produced by cellular respiration, breathing in and out about 500 ml of air during every breath. Oxygen from this air passes into tiny air sacs in the lungs, which are called alveoli, and diffuses into the capillaries that lie just underneath them. From here, the oxygen-rich blood passes to the heart, from where it is pumped around the rest of the body, before being passed back to the lungs to offload carbon dioxide and pick up a fresh supply of oxygen.

Blood delivers oxygen from the lungs, and nutrients from the digestive system, to all cells so that they can respire and carry out all the processes needed for life. When we talk about respiration we often think of the process of breathing, but cellular respiration is a series of chemical reactions that take place in cells to generate the energy that they need to carry out their specific functions.

CONTENTS

a) **Gas exchange**

b) Gas exchange surfaces

c) The human respiratory system

d) Breathing in and out

e) Inspired air and expired air

f) Investigating the effect of exercise on breathing

g) **Respiration**

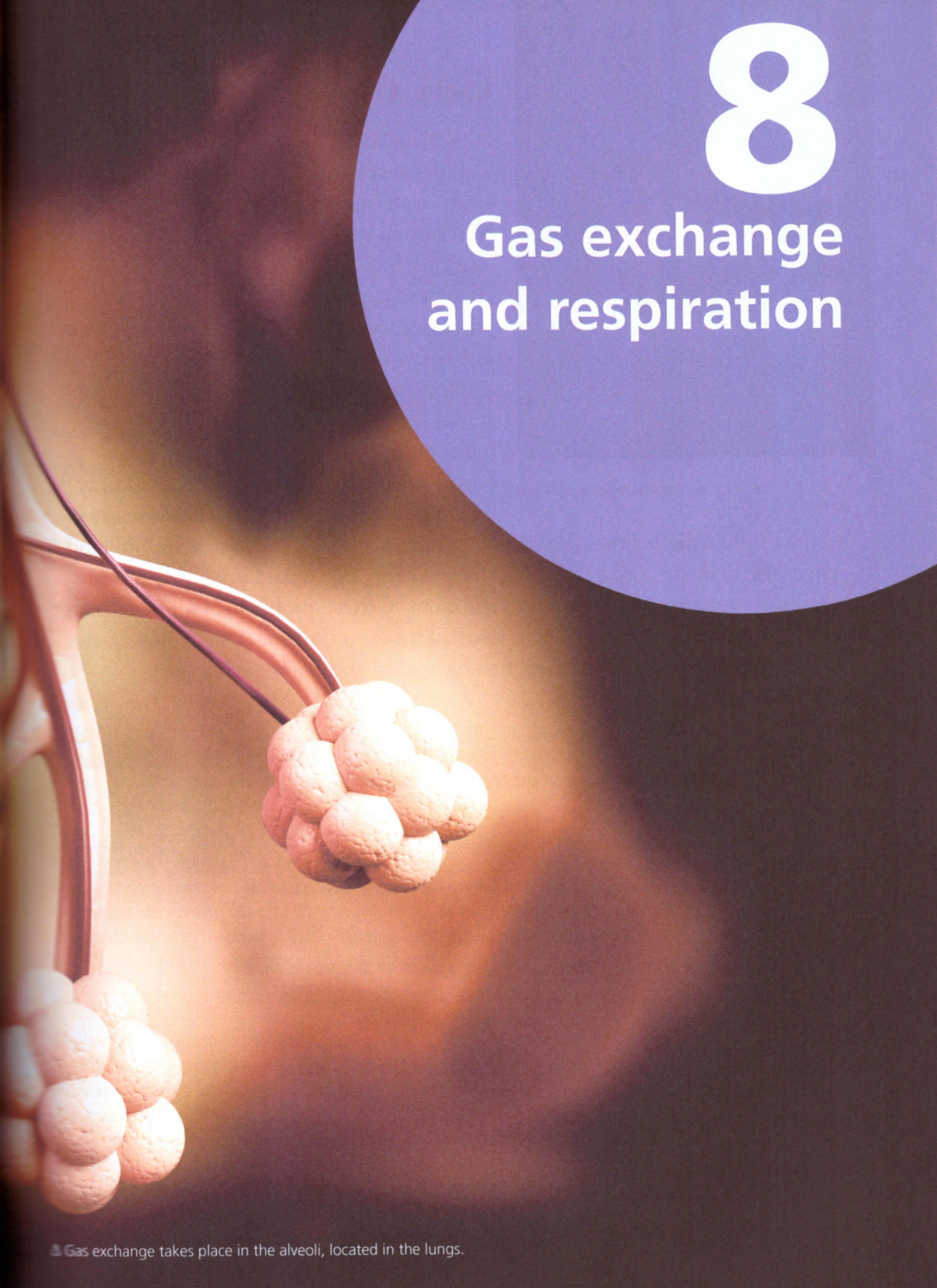
h) Cellular respiration

i) Aerobic respiration

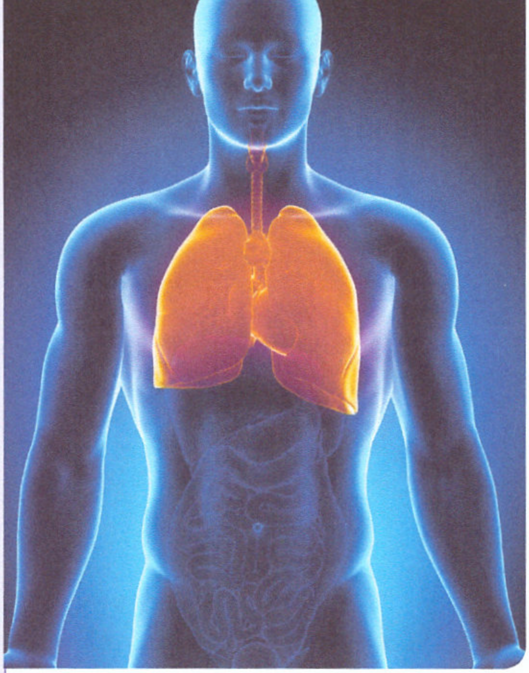
j) Anaerobic respiration

8

Gas exchange and respiration



▲ Gas exchange takes place in the alveoli, located in the lungs.



Δ Fig. 8.1 The lungs are the site of gas exchange in humans.

Gas exchange

INTRODUCTION

Cellular respiration uses substances that are gases in air and produces gases that need to be returned to the environment. These gases must get into and out of the body fast enough to support the rate at which body processes work. For single-celled organisms, this isn't a problem. They have a large surface-area-to-volume ratio, and diffusion across the cell membrane can supply and remove the gases at a fast enough rate. Larger organisms cannot do this. Not only do they have a much smaller surface-area-to-volume ratio, which slows the rate of diffusion, many of them also live on land, where the delicate surface required for gas exchange would dry out. Different groups of organisms have different solutions to these problems. Plants exchange gases inside the leaf; insects have internal tubes (a tracheal system) inside the body where they exchange gases; fish have gills; and many vertebrates, including humans, have lungs.

KNOWLEDGE CHECK

✓ Animals breathe in oxygen from the air and breathe out carbon dioxide.
✓ Humans use lungs for breathing.

LEARNING OBJECTIVES

✓ Identify and name the lungs, diaphragm, ribs, intercostal muscles, larynx, trachea, bronchi, bronchioles, alveoli and associated capillaries.
✓ **EXTENDED** List the features of gas exchange surfaces in humans.
✓ Describe the differences in composition of gases in inspired air and expired air.
✓ **EXTENDED** Explain the differences in composition of gases in inspired air and expired air.
✓ Use limewater as a test for carbon dioxide to investigate the differences in composition between inspired and expired air.
✓ Describe how you would investigate the effect of physical activity on the rate and depth of breathing.
✓ **EXTENDED** Explain why the rate and depth of breathing increase with increasing activity.
✓ **EXTENDED** Explain the role of goblet cells, mucus and ciliated cells in the lungs in protecting against pathogens and particles.

- ✓ **EXTENDED** State that tobacco smoking can cause chronic obstructive pulmonary disease (COPD), lung cancer and coronary heart disease.
- ✓ **EXTENDED** Describe the effects on the gas exchange system of tobacco smoke and its major toxic components.

GAS EXCHANGE SURFACES

Animals need to exchange gases with the environment, to supply oxygen for respiration in cells and to remove the waste product of respiration – carbon dioxide. These gases are exchanged at surfaces by diffusion. So gas exchange surfaces, such as in the human lungs, need adaptations to maximise the rate at which diffusion occurs.

EXTENDED

An effective gas exchange surface has:

- a large surface area
- a short distance over which substances have to diffuse, so cells across which diffusion occurs are usually thin
- a good blood supply
- good ventilation to deliver more oxygen and remove carbon dioxide from the body rapidly.

END OF EXTENDED

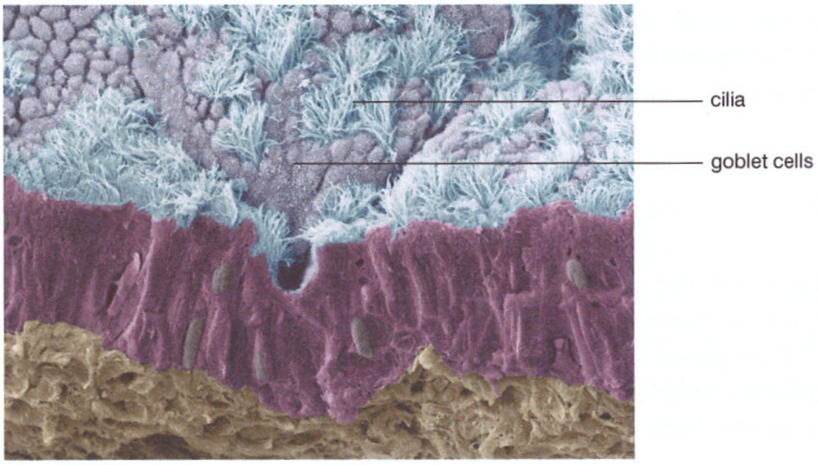
THE HUMAN RESPIRATORY SYSTEM

Breathing is the way that oxygen is taken into our bodies and carbon dioxide is removed. When we breathe, air is moved into and out of our lungs. This involves different parts of the respiratory system within the thorax (the chest cavity).

When we breathe in, air enters though the nose and mouth. In the nose the air is moistened and warmed. The air passes over the **larynx**, where it may be used to make sounds, for example when we talk. The air travels down the **trachea** (windpipe) to the **lungs**. The air enters the lungs through the **bronchi** (singular: **bronchus**), which branch and divide to form a network of **bronchioles**.

EXTENDED

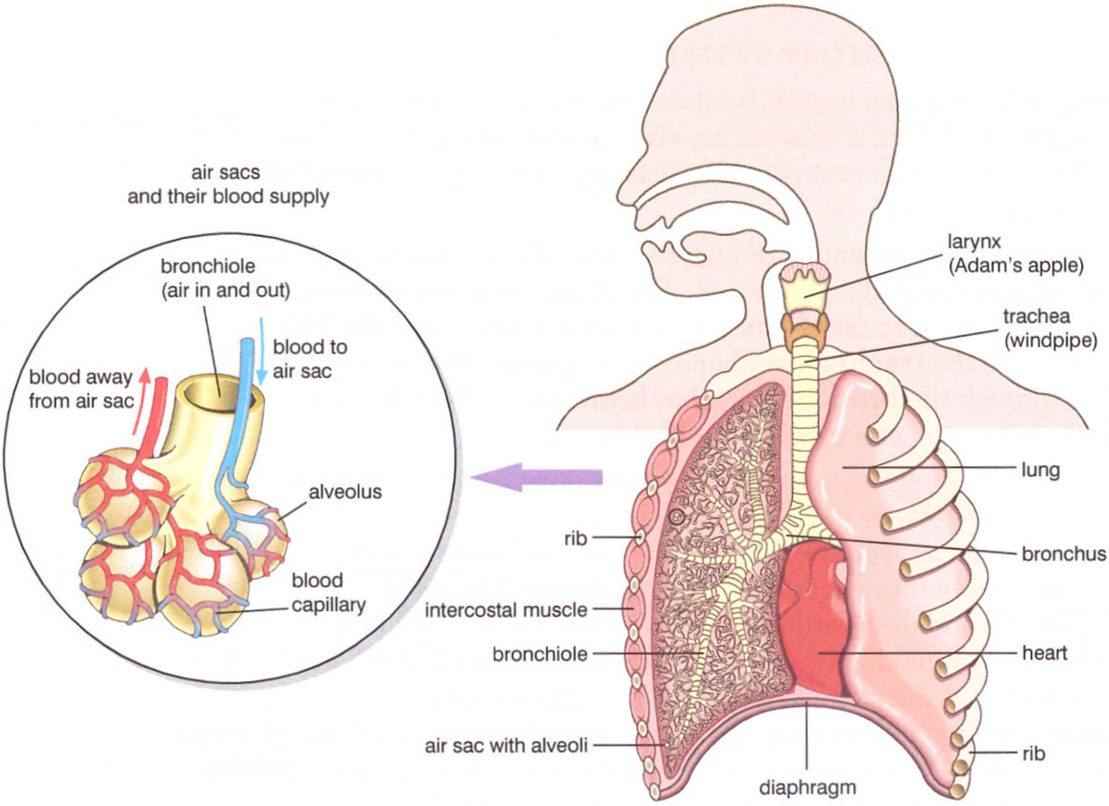
Cells called goblet cells in the lining of the trachea, bronchi and bronchioles secrete **mucus,** which is a slimy liquid. This traps microorganisms and dust particles that are breathed in. The lining of the trachea and bronchi are covered in tiny hairs called **cilia**, which are found on the surface of ciliated cells. The cilia sweep in a co-ordinated motion to move the mucus up from the lungs, up the trachea to the back of the mouth, where it can be swallowed. The combined action of mucus and cilia helps to prevent dirt and microorganisms entering the lungs and causing damage and infection.


cilia
goblet cells

Δ Fig. 8.2 Section through the tracheal epithelium, showing goblet cells, which secrete mucus, and cilia, which sweep the mucus along the epithelial surface.

END OF EXTENDED

At the end of the bronchioles are air sacs. The bulges on an air sac are called **alveoli** (singular: alveolus). The alveoli are covered in tiny blood capillaries. This is where oxygen and carbon dioxide are exchanged between the blood and the air in the lungs. This is called **gas exchange**. The movement of air across the alveolar surface is called **ventilation**.

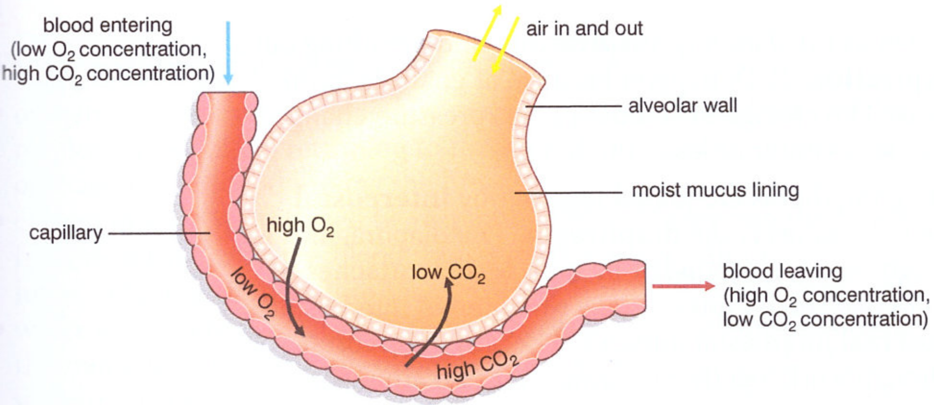

air sacs
and their blood supply
bronchiole
(air in and out)
blood to
air sac
blood away
from air sac
alveolus
blood
capillary
larynx
(Adam's apple)
trachea
(windpipe)
lung
rib
bronchus
intercostal muscle
bronchiole
heart
air sac with alveoli
rib
diaphragm

Δ Fig. 8.3 The human respiratory system.

The alveoli are where oxygen and carbon dioxide diffuse into and out of the blood. For this reason, the alveoli are described as the *site of gas exchange*, or the *respiratory surface*.

The alveoli are adapted for efficiency in exchanging gases by diffusion. They have:

- thin permeable walls, which keep the distance over which diffusion of gases takes place between the air and blood to a minimum
- a moist lining, in which the gases dissolve before they diffuse across the cell membranes
- a large surface area – there are hundreds of millions of alveoli in a human lung, giving a surface area of around 70 m^2 for diffusion
- high concentration gradients for the gases, because the blood is continually flowing past the air sacs, delivering excess carbon dioxide and taking on oxygen, and because of ventilation of the lungs, which refreshes the air in the air sacs.


blood entering (low O_2 concentration, high CO_2 concentration)
air in and out
alveolar wall
moist mucus lining
capillary
high O_2
low O_2
low CO_2
high CO_2
blood leaving (high O_2 concentration, low CO_2 concentration)

Δ Fig. 8.4 Gas exchange in an air-filled alveolus.

REMEMBER

For the highest marks, be careful how you describe the process of gas exchange between the air in the lungs and the blood. Remember that diffusion is a passive process, so that it only occurs while there is a concentration gradient. Avoid answering in simple terms, which imply that the movement of oxygen is only from the air to the blood, and that the movement of carbon dioxide is only from the blood to the air. Make it clear that diffusion happens in all directions randomly and the overall direction of diffusion occurs because of the concentration gradient.

QUESTIONS

1. Explain, as fully as you, can why the lungs show adaptations for a rapid rate of diffusion.
2. List the structures of the human respiratory system and, for each structure, explain its role in breathing.
3. Sketch a diagram of an alveolus and annotate it to show how it is adapted for efficient gas exchange. (Hint: remember to refer to diffusion.)
4. EXTENDED What is the role of the cilia and mucus in the human respiratory system?

EXTENDED

BREATHING IN AND OUT

Breathing in is known as *inhalation* or **inspiration**, and breathing out as *exhalation* or **expiration**. Both happen because of changes in the volume of the thorax. The change in volume causes pressure changes, which in turn cause air to enter or leave the lungs.

The ribs surrounding the thorax are joined together by **intercostal muscles**, and below the lungs is the **diaphragm**. The diaphragm is a domed sheet of tough tissue, surrounded by muscle, that attaches to the thorax. There are two sets of intercostals: the internal intercostal muscles and the external intercostal muscles. The ribs, intercostal muscles and diaphragm work together to bring about breathing or ventilation of the lungs.

In gentle breathing, only the diaphragm may be involved. In deeper breathing, such as during exercise, or if we think about it, the ribs and intercostal muscles become involved.

END OF EXTENDED

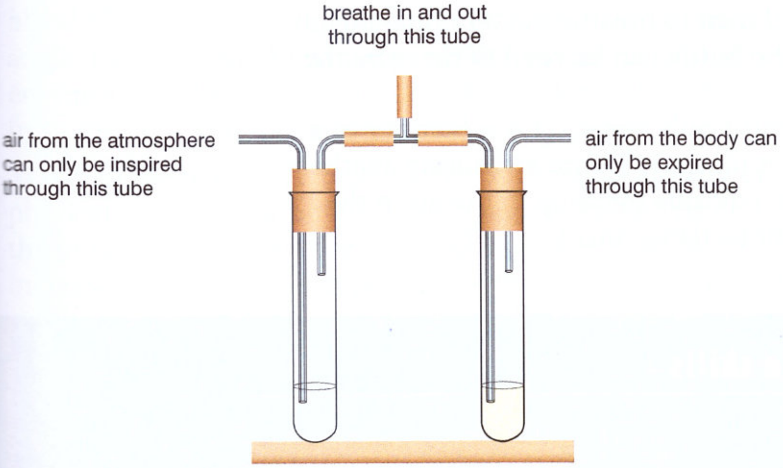
INSPIRED AIR AND EXPIRED AIR

The air we breathe in and out contains many gases. Oxygen is taken into the blood from the air we breathe in. Carbon dioxide and water vapour are added to the air we breathe out. The other gases in the air we breathe in are breathed out again almost unchanged, except for being warmer.

	In inspired air	**In expired air**
oxygen	21%	16%
carbon dioxide	0.04%	4.5%
water	variable	high

Δ Table 8.1 Differences in composition of inspired and expired air.

We can compare the carbon dioxide in inspired air and expired air using the apparatus shown in Fig. 8.5. Limewater reacts with carbon dioxide and turns cloudy, so this is a test for carbon dioxide.


breathe in and out through this tube
air from the atmosphere can only be inspired through this tube
air from the body can only be expired through this tube

Δ Fig. 8.5 Limewater in the tubes shows that expired air contains much more carbon dioxide than inspired air. Note: one-way valves must be used when setting up this apparatus.

EXTENDED

The composition of inspired and expired air changes because:

- oxygen is removed from blood by respiring cells and used for cellular respiration, so blood returning to the lungs has a lower concentration of oxygen than blood leaving the lungs
- carbon dioxide is produced by respiration and diffuses into the blood from respiring cells; the blood transports the carbon dioxide to the lungs, where it diffuses into the alveoli
- water vapour concentration increases because water evaporates from the moist linings of the alveoli into the expired air as a result of the warmth of the body.

Other gases remain unaffected because they are not used or produced by the body.

END OF EXTENDED

INVESTIGATING THE EFFECT OF EXERCISE ON BREATHING

There are two aspects of breathing that can change during exercise – the rate of breathing and the volume of breath.

- Rate of breathing is usually counted as number of breaths per minute.
- The volume of a breath can be measured in dm^3 using a spirometer. A simple spirometer can be made using a 2-litre plastic bottle that has been marked down the side with volumes of water. (This can be done by adding 500 cm^3 of water at a time, and marking the volume on the side of the bottle with a waterproof marker.) When the bottle is full of water, turn it upside-down into a water trough without allowing any air into the bottle. Insert a flexible plastic tube into the neck of the bottle and secure the bottle and tube in position. Clean the other end of the tubing with antiseptic solution. (Alternatively, add a mouthpiece to the end of the tubing that can easily be removed and sterilised after each test.) To measure the volume of a breath, ask the

person to wear a noseclip and then to breathe out a normal breath into the tube. The scale on the bottle can be used to measure the volume of air breathed out.

(Safety note: this apparatus must only be used for measuring one breath. The bottle must be set up again before measuring another breath. This is because carbon dioxide build-up in the air in the bottle over several breaths can be dangerous.)

Developing investigative skills

Devise and plan investigations

❶ Design an investigation into the effect of exercise on breathing. (Hint: think carefully about how many people to test, and how to test them, in order to get reliable results.)

Demonstrate and describe techniques

❷ This investigation could involve vigorous exercise. What risks will you need to prepare for, and how should they be minimised?

Analyse and interpret data

The data in the table are the results from an investigation into the effect of exercise on breathing in four people. They were first tested at rest and then after 2 minutes of running on a treadmill set at the same speed.

Person	A		B		C		D	
	Rate (breaths/ minute	Breath volume (dm^3)	Rate (breaths/ minute	Breath volume (dm^3)	Rate (breaths/ minute	Breath volume (dm^3)	Rate (breaths/ minute	Breath volume (dm^3)
at rest	13	0.5	15	0.4	12	1.2	18	0.6
after exercise	19	1.3	23	0.9	18	1.3	26	1.5

❸ Explain how these data should be adjusted before they can give a reliable answer to the question 'How does exercise affect breathing?'

The results of an investigation like the one in the Developing investigative skills box should show that both the rate of breathing and depth of breathing increase with the level of activity. However, a trained athlete will show a smaller change in rate and depth of breathing than an untrained person.

EXTENDED

The rate and depth of breathing increase with level of activity because as the muscles contract faster they respire faster and so make carbon dioxide more quickly. Carbon dioxide is an acidic gas that dissolves easily in water-based solutions, such as the cytoplasm of a cell and blood plasma. The more carbon dioxide there is in solution, the more acidic the solution. A change in pH can affect the activity of many cell enzymes (see Topic 4), so it is important that carbon dioxide is removed from the cells and the body as quickly as possible.

The increase in carbon dioxide concentration as a result of increased physical activity is detected as the blood flows past receptors in part of the brain. The receptors send impulses to the lungs, causing an increase in the rate and depth of breathing, which helps to remove the extra carbon dioxide as quickly as possible.

SCIENCE IN CONTEXT

HOW BREATHING RATE IS CONTROLLED

Rate of breathing is controlled by part of the brain that measures, not the oxygen concentration of the blood, but the carbon dioxide concentration. This is because a small increase in carbon dioxide concentration in body fluids could have a much more damaging effect on the body than a small decrease in oxygen concentration.

Smoking-related diseases

Tobacco smoke contains a mixture of chemicals, many of which are dangerous to cells. Over time the damage can lead to several diseases: **chronic obstructive pulmonary disease (COPD)**, which is a collection of lung diseases that includes **bronchitis** and **emphysema**; lung cancer and coronary heart disease.

Carbon monoxide takes the place of oxygen in haemoglobin and prevents the body from absorbing as much oxygen.

Nicotine is addictive and narrows blood vessels, increasing blood pressure and the risk of coronary heart disease.

Tar is a sticky substance that coats the cells of the trachea, bronchi and bronchioles, leading to coughing and cell damage. This gives a decrease in the rate of gas exchange and can lead to cancer of the lungs, mouth and throat.

END OF EXTENDED

QUESTIONS

1. Describe the differences in composition between inspired air and expired air.
2. Describe the effects of exercise on the rate and depth of breathing.
3. EXTENDED Explain the differences in composition between inspired air and expired air.
4. EXTENDED Explain what would happen to cells if rate and depth of breathing did not change during exercise.

End of topic checklist

Key words

alveoli, bronchus, bronchiole, cilia, diaphragm, gas exchange, intercostal muscles, larynx, lungs, mucus, trachea, ventilation

During your study of this topic you should have learned:

○ **EXTENDED** That humans exchange gases with the environment by diffusion, so the lungs need a large surface area, a short distance for diffusion to the blood, and continual ventilation of the inside of the lungs.

○ To describe ventilation as the breathing in and out of air to the lungs, through the larynx, where sound may be produced, down the trachea to the two bronchi, and through the bronchioles to the alveoli, where the gases are exchanged with the many capillaries that lie next to the alveoli.

○ Expired air contains more carbon dioxide, less oxygen and more water vapour than inspired air.

○ **EXTENDED** The differences in gas concentration in inspired air and expired air are the result of respiration in cells using oxygen and producing carbon dioxide, and the evaporation of water vapour from surfaces inside the lungs.

○ An increased level of activity increases the rate and depth of breathing.

○ **EXTENDED** The increased rate and depth of breathing during activity removes the increased amount of carbon dioxide produced by respiration and so stops the pH of body tissues and blood falling.

○ Goblet cells in the linings of the lungs secrete mucus that traps pathogens and particles. The mucus is swept out of the lungs by cilia, which protects the lungs from damage and infection.

End of topic questions

Note: The marks given for these questions indicate the level of detail required in the answers. In the examination, the number of marks given to questions like these may be different.

1. **a)** Define the terms *diffusion* and *gas exchange* **(2 marks)**

   b) Describe the role of diffusion in gas exchange in humans. **(2 marks)**

   c) EXTENDED Explain how the tissues and organs of the lungs are adapted to maximise the rate of gas exchange. **(4 marks)**

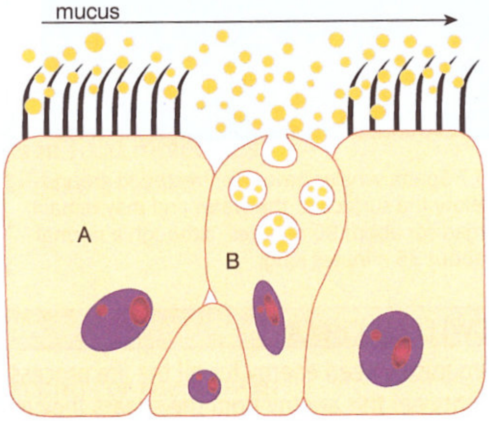
2. EXTENDED Fig. 8.6 shows a few cells of the epithelium lining the trachea.

   a) State where the trachea is found and explain its role in the body. **(2 marks)**

   b) Name the type of cell shown by cell A and describe its function. **(2 marks)**

   c) Name the type of cell shown by cell B and describe its function. **(2 marks)**

   d) Explain the role of these cells in protecting the body. **(3 marks)**



Δ Fig. 8.6 Cells of the trachea epithelium

Δ Fig. 8.7 Sperm whales have been recorded around 3 km below the surface of the water and may remain submerged for about 90 minutes, although a normal dive is about 35 minutes long.

Respiration

INTRODUCTION

The current record for a human holding their breath under water is about 11.5 minutes, although this can be extended by starting with a breath of pure oxygen. For most people, this length of time would be impossible, and the urge to breath would become overwhelming after 2 or 3 minutes. Even people who are well trained for this risk damage to cells – particularly brain cells, which need a constant supply of oxygen to function properly. These records are small in comparison with those for diving whales, some of which may be underwater for over an hour.

KNOWLEDGE CHECK

- ✓ Organisms need energy for all the life processes that keep them alive.
- ✓ Plants get this energy from the sugars they make in photosynthesis.
- ✓ Animals get this energy from their food.
- ✓ Plants take in oxygen and give out carbon dioxide as a result of photosynthesis.

LEARNING OBJECTIVES

- ✓ **EXTENDED** Define *aerobic respiration* as the chemical reactions in cells that use oxygen to break down nutrient molecules to release energy.
- ✓ Give examples of how energy released from respiration is used in the human body.
- ✓ **EXTENDED** Define *aerobic* and *anaerobic respiration*.
- ✓ State the word equation for aerobic respiration as:
  glucose + oxygen → carbon dioxide + water
- ✓ **EXTENDED** State the balanced symbol equation for aerobic respiration as:
  $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$
- ✓ **EXTENDED** Describe *anaerobic respiration* as the chemical reactions in cells that break down nutrient molecules to release energy without using oxygen.
- ✓ **EXTENDED** State the word equation for anaerobic respiration in muscles during vigorous exercise as:
  glucose → lactic acid
- ✓ **EXTENDED** State the word equation for anaerobic respiration in yeast as:
  glucose → alcohol + carbon dioxide
- ✓ **EXTENDED** State that much less energy is released from glucose in anaerobic than in aerobic respiration.
- ✓ **EXTENDED** Describe how lactic acid concentration increases in muscles and in blood during vigorous exercise. State that lactic acid builds up in muscles and blood during vigorous exercise, causing an oxygen debt.
- ✓ **EXTENDED** Describe the role of anaerobic respiration in yeast during bread-making.

CELLULAR RESPIRATION

When we talk about respiration generally, we usually mean breathing (or ventilation), when gases are exchanged across a respiratory surface. Here we are focusing specifically on **cellular respiration**, which is the release of energy from the chemical bonds in food molecules such as glucose. This only takes place inside cells, and every living cell carries out cellular respiration.

REMEMBER

Be clear in your answers that you are using the term *respiration* to mean *cellular respiration*, and to use *ventilation* not *respiration* when talking about breathing.

Every cell in a living organism requires energy, and this energy comes from respiration, which is the breakdown of chemical bonds in food molecules such as glucose to release energy in a form that can be used in cells.

In human cells, this energy is used:

- to produce the contraction of muscle cells
- to produce new chemical bonds during the **synthesis** (formation) of new protein molecules
- to produce new chemicals needed for cell division and for the growth of cells
- for the active transport of molecules across cell membranes
- to produce the movement of nerve impulses along nerve cells
- for the maintenance of a constant core body temperature.

Note that we usually refer to glucose as the *nutrient molecule* or *food molecule* that is broken down in respiration. This is because it is the molecule most commonly used in this reaction in the body. If glucose is in short supply, then other molecules may be used instead from the breakdown of fats or proteins.

Respiration is a series of reactions and, like other reactions in cells, these are controlled by enzymes. So any change in a cell that affects enzymes (such as a change in temperature or pH) will affect the rate of respiration (see Topic 4).

AEROBIC RESPIRATION

EXTENDED

Most plant and animal cells use oxygen during cellular respiration. Respiration that uses oxygen to release energy from glucose in chemical reactions in cells is called **aerobic respiration**. Water and carbon dioxide are produced as waste products. This is very similar to burning fuel, except that in our bodies enzymes control the process.

END OF EXTENDED

Aerobic respiration can be summarised by a word equation:

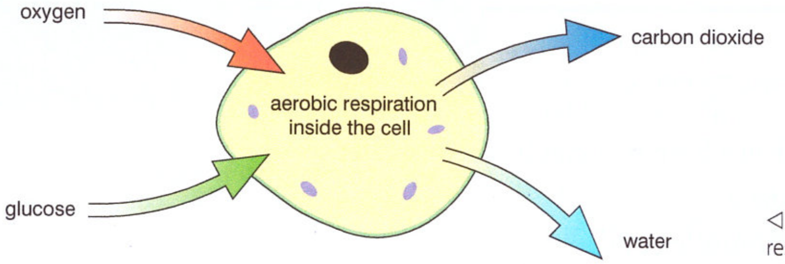
glucose + oxygen → water + carbon dioxide (+ energy)

EXTENDED

It can also be written as a symbol equation:

$C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2$ (+ energy)

END OF EXTENDED



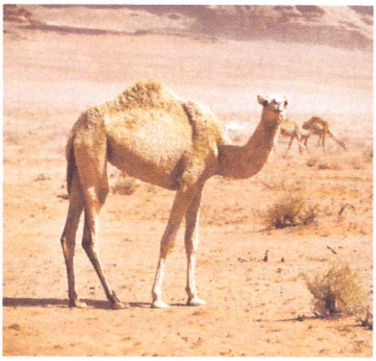
◁ Fig. 8.8 Aerobic respiration in a cell.

The oxygen needed for respiration comes from the air (except for a small proportion in photosynthesising plants, which comes from photosynthesis). The carbon dioxide from cellular respiration is released to the air, and the water is either used in the body or excreted through the kidneys.

SCIENCE IN CONTEXT

WATER FROM RESPIRATION

A camel can survive for many days without drinking liquid water, which means it survives well in desert conditions. The camel's hump is not a store of water, but a store of fat. Over a long period without food, the fat is broken down to release substances for aerobic respiration. As water is one of the products of aerobic respiration, this also helps the camel to survive longer without drinking water.



Δ Fig. 8.9 Wild camels live in dry areas and so must go many days without drinking water.

A complete lack of food and drinking water are conditions that would kill a human in a few days, because we don't metabolise fat as well as the camel does, or retain water as well. So, before setting out into the desert for a long trip, make sure your camel has a large hump (and you have plenty of food and water).

During aerobic respiration, many of the chemical bonds in the glucose molecule are broken down. This releases a lot of energy: around 2900 kJ of energy is released for each mole of glucose molecules used in aerobic respiration.

QUESTIONS

1. a) Write out the word equation for aerobic respiration.
   b) Annotate your equation to show where the reactants come from.
   c) Annotate your equation to show what happens to the products of the reaction in a human.
   d) Describe how your answers to parts (b) and (c) might differ for a camel on a long journey without water, and explain your answer.
2. Where does respiration take place in the body?
3. Give three examples of the use of energy from respiration in the human body.
4. EXTENDED Write the balanced symbol equation for aerobic respiration.

SCIENCE LINK

CHEMISTRY – PHYSICAL AND CHEMICAL CHANGES, STOICHIOMETRY

- Respiration is a chemical change that releases energy; the energy changes occur as a result of bond-breaking and bond-making.
- Using word equations and balanced symbol equations to describe chemical changes helps us to understand the particle interactions that are taking place.

PHYSICS – ENERGY

- Energy is released during respiration and this links to several key ideas about energy.
- Ideas about conservation of energy indicate how much glucose is required to maintain a healthy organism and how that might change depending on age and lifestyle.
- Energy transfers are not always useful and this links to processes for maintaining body temperature as energy often transfers as heat.
- Efficiency measures how much of the energy released is *useful* in comparison to the total energy available.

EXTENDED

ANAEROBIC RESPIRATION

Aerobic respiration supplies most of the energy that plant cells and animal cells need most of the time. However, there are times when not enough oxygen is available for aerobic respiration to be carried out fast enough to deliver all the energy that is needed – for example:

- in diving animals, such as whales and seals
- in muscle cells, when vigorous exercise requires more energy than can be provided by an increased supply of oxygen from deeper faster breathing and a faster heart rate.

In these cases, the additional energy needed is supplied by **anaerobic respiration** (sometimes called *fermentation*). This kind of respiration also releases energy from glucose molecules, but without the need for oxygen.

Some organisms, such as yeast (a unicellular fungus) and some bacteria may respire anaerobically in preference to aerobic, respiration, even when oxygen is present.

In anaerobic respiration, the glucose molecule is only partly broken down, so far less energy is released from each glucose molecule in anaerobic respiration compared with aerobic respiration. Only about 150 kJ is produced from every mole of glucose molecules respired anaerobically in a muscle cell.

Anaerobic respiration in muscle cells

When animal cells respire anaerobically, such as muscle cells during vigorous exercise, the glucose is broken down to lactic acid:

glucose → lactic acid (+ energy)

Only the word equation for anaerobic respiration is required, but the balanced symbol equation for this reaction is:

$$C_6H_{12}O_6 \rightarrow 2C_3H_6O_3$$

Note that, even when a muscle cell is respiring anaerobically, aerobic respiration is also taking place and using all the oxygen that is available. Where aerobic respiration cannot supply all the energy needed, only the additional energy needed comes from anaerobic respiration.

SCIENCE IN CONTEXT

RESPIRATION IN ATHLETICS

If you watch carefully, you will not see a sprint athlete breathe during a race. At the start of the race there will be some oxygen in their muscle cells, but this is rapidly used up as they start running. Anaerobic respiration provides virtually all of the energy used in a 100 m sprint by a well-trained athlete.

Δ Fig. 8.10 A fit athlete in the middle of a sprint is using almost entirely anaerobic respiration.

Sprinting cannot be maintained for long, because the muscle cells also need a rapid supply of glucose for respiration. So longer distance races are managed using a combination of aerobic and anaerobic respiration. In marathons, most of the race is run aerobically, with only the last stretch being managed as a sprint using anaerobic respiration.

During anaerobic respiration, the concentration of lactic acid builds up in the cells and in the blood. When exercise has finished and sufficient oxygen is available again, a fast heart rate is maintained for a while to help transport lactic acid to muscle and liver cells. Fast breathing also continues to supply the additional oxygen for breaking down the lactic acid. The lactic acid is converted in muscle and liver cells back to glucose, for use in aerobic respiration later, or broken down fully, using oxygen, to carbon dioxide and water.

The additional oxygen needed after exercise used to be called the **oxygen debt**, but it is now known that additional oxygen is needed after any prolonged exercise, even if completely aerobic, to return many processes in the body back to their resting state. This need, which you can feel when you breathe more deeply after exercise, is now called *excess post-exercise oxygen consumption* (EPOC).

Anaerobic respiration in yeast cells

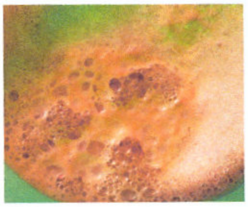
Yeast cells break down glucose without using oxygen, even if oxygen is present. The word equation for this reaction is:

glucose → ethanol + carbon dioxide (+ energy)

Only the word equation for anaerobic respiration is required, but the balanced symbol equation for anaerobic respiration in yeast cells is:

$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$ (+ energy)

We make use of this reaction when we use yeast in brewing to make beer and wine. The ethanol is formed when sugars in the barley or grapes is broken down. Ethanol causes the alcoholic effects that occur when we drink these drinks. We also use yeast in bread-making, because the carbon dioxide released forms bubbles in the dough, making the bread light and spongy.



Δ Fig. 8.11 The froth on top of this yeast culture is carbon dioxide from anaerobic respiration escaping from the mixture.

END OF EXTENDED

QUESTIONS

1. EXTENDED Explain why muscle cells sometimes need to respire anaerobically.
2. EXTENDED Describe the similarities and differences between anaerobic respiration in yeast cells and in animal cells.
3. EXTENDED Compare the amount of energy released during aerobic respiration and anaerobic respiration of glucose in a muscle cell.
4. EXTENDED Explain why bread dough rises and becomes soft and spongy if it is kept warm.

End of topic checklist

Key words

aerobic respiration, anaerobic respiration, cellular respiration, oxygen debt, synthesis

During your study of this topic you should have learned:

○ About the uses of energy in the human body, including in muscle contraction, protein synthesis, cell division, growth and the maintenance of a constant body temperature.

○ **EXTENDED** How to define anaerobic and aerobic respiration.

○ That in aerobic respiration, glucose is broken down using oxygen from the air:
glucose + oxygen → carbon dioxide + water (+ energy)
EXTENDED $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ (+ energy)

○ **EXTENDED** Anaerobic respiration occurs in muscle cells when not enough oxygen is available to supply the energy needed for contraction during vigorous exercise.

○ **EXTENDED** That in anaerobic respiration in animal cells, glucose is broken down to lactic acid which may be called the oxygen debt:
glucose → lactic acid (+ energy)
$C_6H_{12}O_6 \rightarrow 2C_3H_6O_3$ (+ energy)

○ **EXTENDED** The lactic acid produced needs to be broken down in muscle and liver cells after anaerobic respiration ends, and this needs additional oxygen.

○ **EXTENDED** That in anaerobic respiration in yeast cells, glucose is broken down to ethanol:
glucose → ethanol + carbon dioxide (+ energy)
$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$ (+ energy)

○ **EXTENDED** Aerobic respiration releases much more energy from each glucose molecule than anaerobic respiration.

End of topic questions

Note: The marks given for these questions indicate the level of detail required in the answers. In the examination, the number of marks given to questions like these may be different.

1. **a)** List the body systems in a human that are involved in supplying the reactants of cellular respiration. **(3 marks)**

b) List the body systems in a human that are involved in removing the products of cellular respiration. **(3 marks)**

2. EXTENDED Draw up a table to summarise the similarities and differences between aerobic and anaerobic respiration. **(8 marks)**

3. EXTENDED A whale takes a deep breath of air and then dives for half an hour. Suggest how energy would be generated in the whale's muscles over the period of the dive. **(4 marks)**

4. EXTENDED In bread-making, the yeast is first mixed with a solution containing sugar and kept in a warm place until a froth forms on the surface. The yeast mixture is then added to flour and any additional constituents, and mixed thoroughly. The dough is placed in a warm place for a while, until it has doubled in size. It is then baked as a loaf.

a) Explain why a sugar solution is added to the yeast at the start. **(2 marks)**

b) 'A warm place' means around 25–30 °C.

i) Explain what would happen if the temperature was lower than this. **(3 marks)**

ii) Explain what would happen if the temperature was higher than this. **(3 marks)**

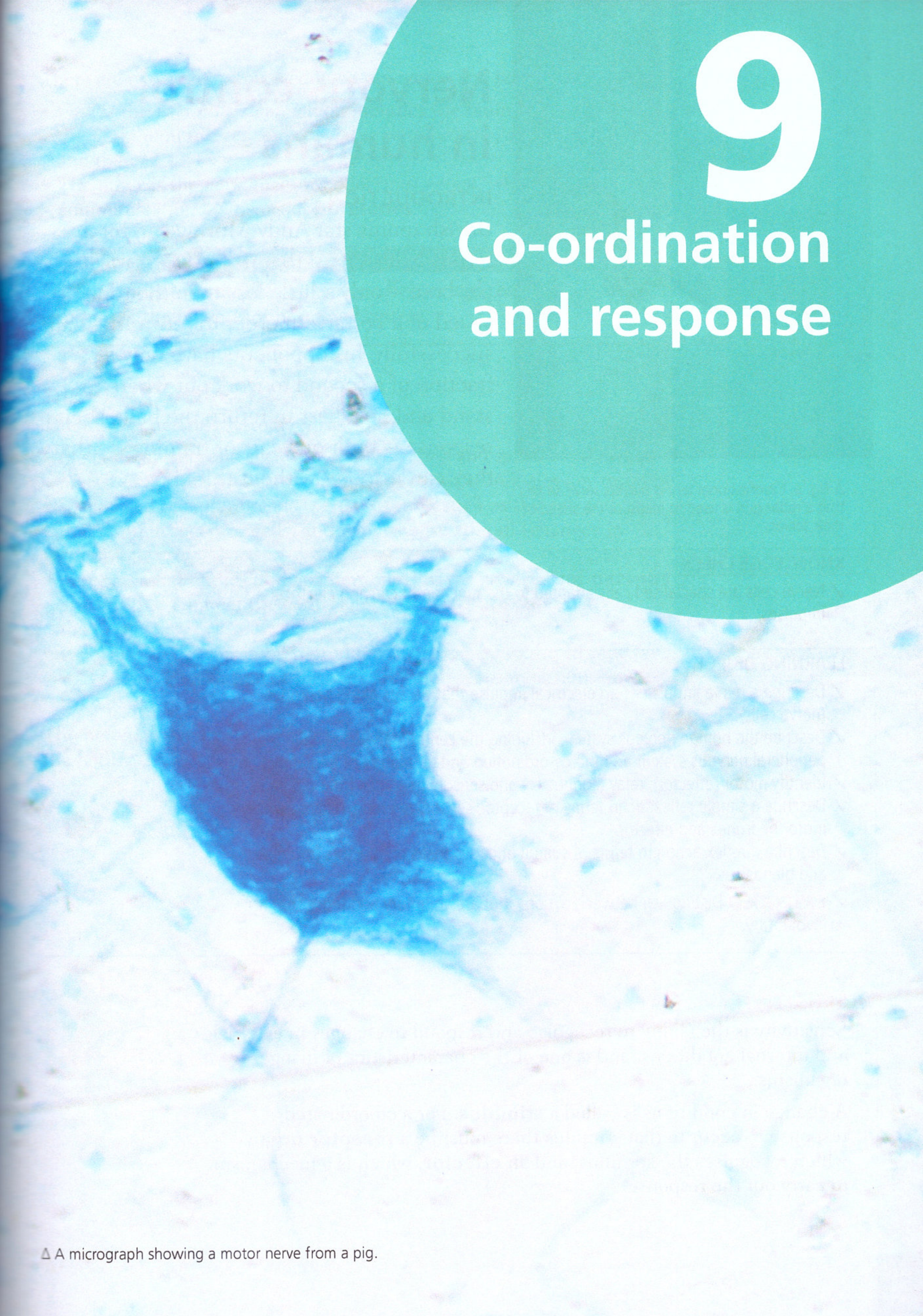
The human nervous system is the body's control and communications network that uses chemicals and electrically conducting nerve cells to detect, interpret and respond to changes within the body and in the environment. The nervous system tells the body how to react to these changes by sending electrochemical impulses to organs such as the muscles, blood system and skin. The longest nerve cell in the body is the sciatic nerve, which stretches from the base of the spine to the big toe in each foot!

CONTENTS

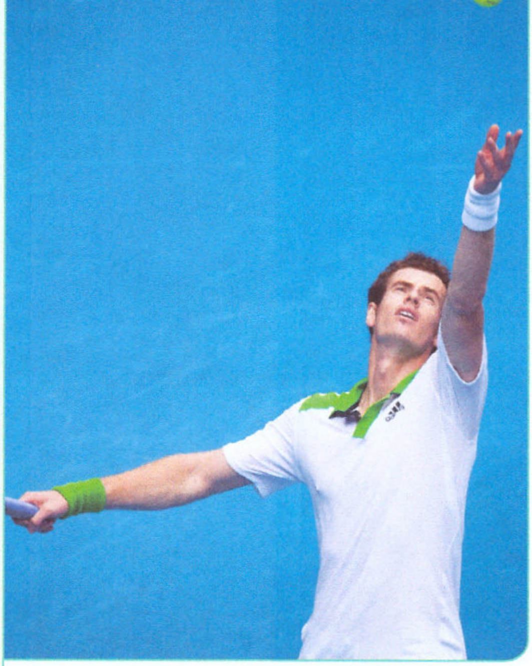
a) **Nervous control in humans**
b) Sensitivity
c) The human nervous system
d) **Sense organs**
e) Human sense organs
f) **Hormones**
g) Hormones in humans
h) **Homeostasis**
i) Homeostasis in humans
j) **Tropic responses**
k) Responses in plants

9

Co-ordination and response



∆ A micrograph showing a motor nerve from a pig.



Δ Fig. 9.1 Professional tennis players serve so fast that a radar gun is used to measure the speed of their serves.

Nervous control in humans

INTRODUCTION

British tennis star Andy Murray can hit a tennis ball so hard that it travels at 227 km per hour – only a little less than the top speed of a Ferrari. In order to return the ball successfully, his opponents have only a fraction of a second to work out where to stand and how best to return the ball. Their response is built on years of training, so that they can respond without thinking.

KNOWLEDGE CHECK

✓ Nerve cells are specialised cells adapted to the function of carrying electrical impulses.

LEARNING OBJECTIVES

✓ Describe a nerve impulse as an electrical impulse that passes along neurones (nerve cells).

✓ Describe the human nervous system, including the central nervous system, the peripheral nervous system and the co-ordination and regulation of body functions.

✓ Identify motor (effector), relay (connector) and sensory neurones from diagrams.

✓ Describe a simple reflex arc in terms of receptor, sensory neurone, relay neurone, motor neurones and effector.

✓ Describe a reflex action in terms of stimuli and responses of effectors (muscles and glands).

✓ **EXTENDED** Distinguish between actions that are voluntary and those that are involuntary.

SENSITIVITY

Sensitivity is the ability to recognise and respond to changes in external and internal conditions, and is one of the characteristics of living organisms.

A change in conditions is called a **stimulus**. For a co-ordinated response to occur to that stimulus there must be a **receptor organ**, which recognises the stimulus, and an **effector**, which is a mechanism to carry out the response.

There are two systems involved in co-ordination and response in humans.

- One is the *nervous system*, which includes the brain, the spinal cord, the peripheral **nerves** and specialist sense organs, such as the eye and the ear.
- The other is the *hormonal* (or endocrine) *system*, which uses chemical communication by means of **hormones**.

REMEMBER

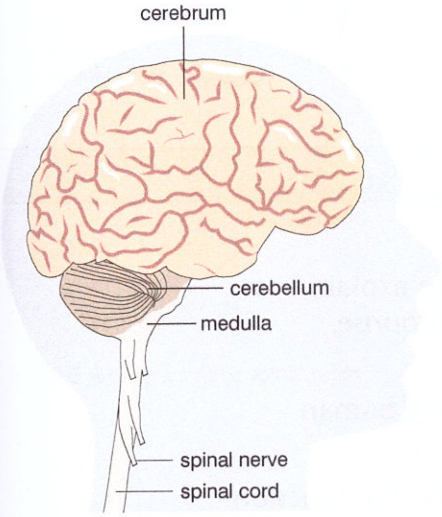
Try to identify the stimulus, receptor, effector and response in any example of the nervous or hormonal system.

THE HUMAN NERVOUS SYSTEM

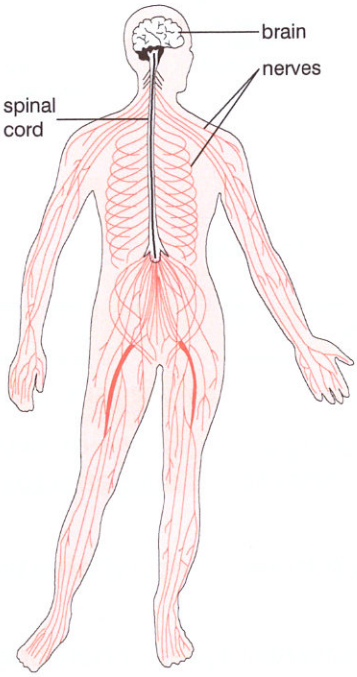
The human nervous system consists of:

- the **central nervous system** (CNS; the brain and spinal cord), which processes nervous impulses from the body and co-ordinates any response
- specialised receptor organs (**sense organs** such as the eye and ear) that contain receptor cells, and which sense stimuli (changes in conditions)
- nerves (large bundles of many neurones) of the **peripheral nervous system** that connect the central nervous system to other parts of the body
- specialised effectors, which produce the response to the stimulus, such as the contraction of muscles and the secretion of hormones from glands.

The nervous system co-ordinates and regulates many functions in the body.



Δ Fig. 9.2 The human central nervous system (CNS).

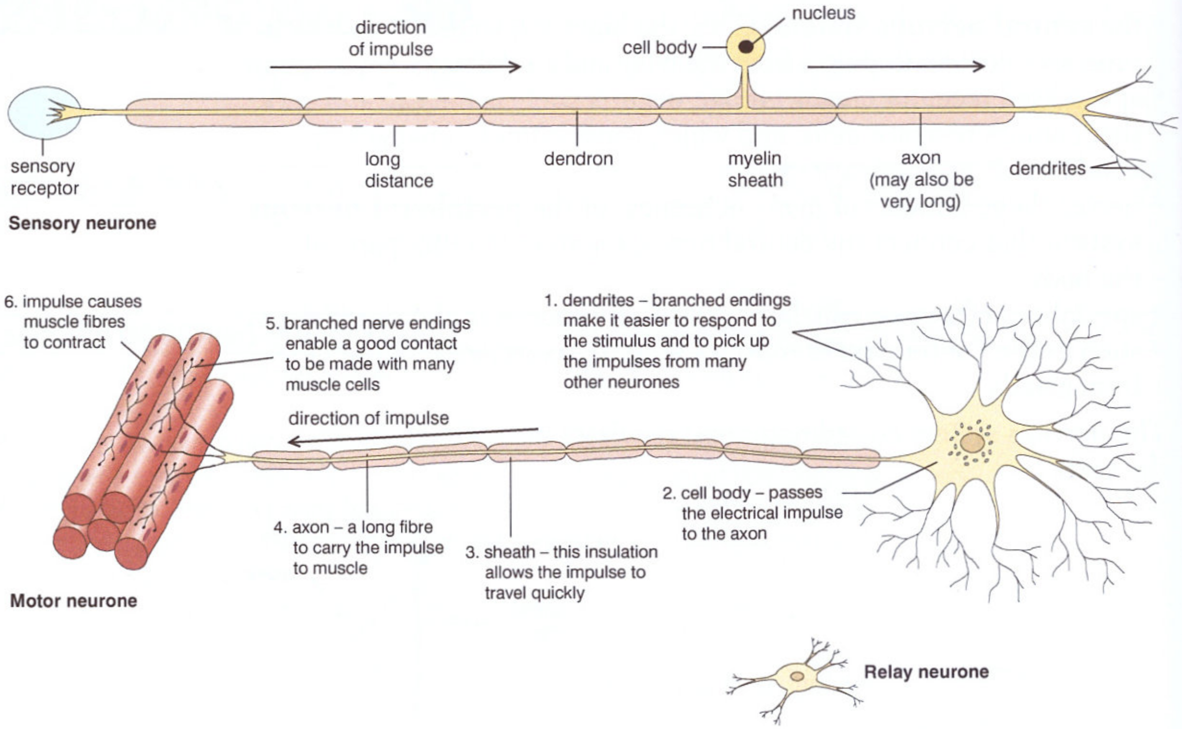


Δ Fig. 9.3 The human nervous system.

Neurones

Nerves connect the sense organs to the central nervous system. Nerves, and the brain and spinal cord are made of specialised nerve cells called **neurones**. These cells are specially adapted for their function because they have many endings that connect with other neurones, for passing on electrical impulses, and cell extensions, called axons and dendrons, that carry the electrical impulses.

- Neurones that link sense organs to the central nervous system are called **sensory neurones**.
- Neurones within the central nervous system may be very short, and are called **relay neurones** (or sometimes *intermediate* or *connector* neurones).
- Neurones that connect the central nervous system to an effector, such as a muscle, are called **motor neurones** (or *effector* neurones).


direction of impulse
nucleus
cell body
sensory receptor
long distance
dendron
myelin sheath
axon (may also be very long)
dendrites
Sensory neurone
6. impulse causes muscle fibres to contract
5. branched nerve endings enable a good contact to be made with many muscle cells
1. dendrites – branched endings make it easier to respond to the stimulus and to pick up the impulses from many other neurones
direction of impulse
2. cell body – passes the electrical impulse to the axon
4. axon – a long fibre to carry the impulse to muscle
3. sheath – this insulation allows the impulse to travel quickly
Motor neurone
Relay neurone

Δ Fig. 9.4 Different types of neurone.

QUESTIONS

1. Explain what is meant by the term *sensitivity*.
2. Use the following words in one or two sentences to explain how the body responds to change: *effector, receptor, response, stimulus.*
3. Describe two different kinds of effector organ in the human body.
4. Name three different types of neurone and describe the function of each in the nervous system.

Reflex response

The simplest type of response to a stimulus is a **reflex**. Reflexes are rapid, automatic responses to a specific stimulus and often act to protect you in some way – for example, blinking if something gets in your eye or sneezing if you breathe in dust.

The pathway that impulses travel along during a reflex is called a **reflex arc**:

stimulus → receptor → sensory neurone → relay neurone in CNS → motor neurone → effector → response

Simple reflexes are usually spinal reflexes, which means that the impulses are processed by the spinal cord, not the brain. The spinal cord sends an impulse back to the effector. Effectors are the parts of the body that respond, either muscles or glands. Examples of spinal reflexes include standing on a pin or touching a hot object.

stand on pin → nerve endings → sensory neurone → spinal cord → motor neurone → leg muscles → leg moves

When the spinal cord sends an impulse to an effector, other impulses are sent on to the brain so that it is aware of what is happening. It also allows the brain to over-ride the reflex response. For example, if you were holding a large bowl of hot food that you were looking forward to eating, you might look around quickly for somewhere to put it down rather than drop it immediately and risk breaking the bowl.

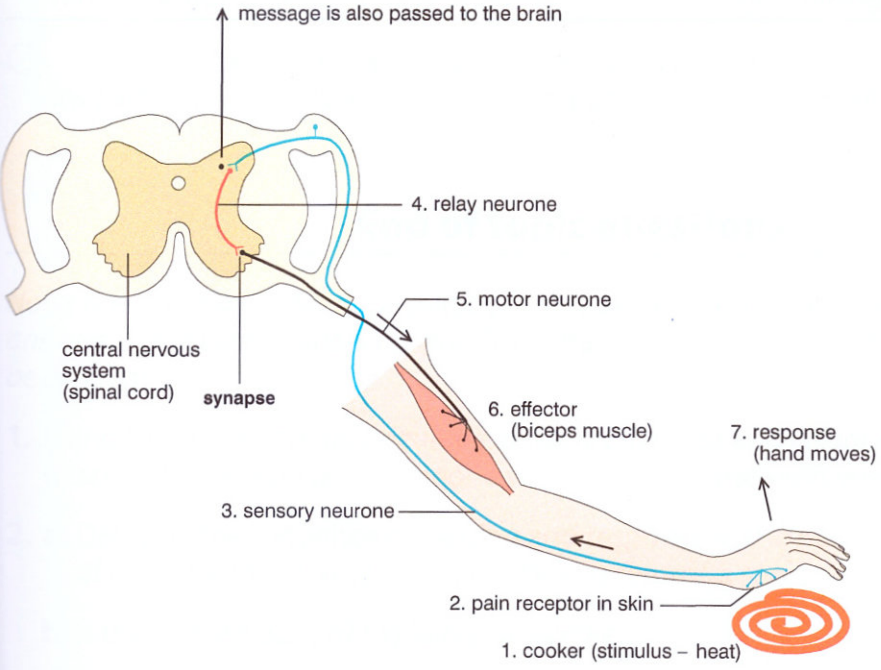

message is also passed to the brain
4. relay neurone
5. motor neurone
central nervous system (spinal cord)
synapse
6. effector (biceps muscle)
7. response (hand moves)
3. sensory neurone
2. pain receptor in skin
1. cooker (stimulus – heat)

Fig. 9.5 A diagrammatic spinal reflex.

REMEMBER

For higher marks you will need to understand the structure and functioning of the reflex arc, and be able to interpret diagrams and describe what happens at each step.

EXTENDED

Reactions that happen automatically, such as those caused by a reflex response, are usually **involuntary**, meaning that the body responds without the conscious control of the central nervous system. Many more of our responses are **voluntary**, meaning that we make a conscious decision, using the brain, to make that response and not a different one. Involuntary actions are usually essential to basic survival and are rapid, whereas voluntary responses often take longer.

END OF EXTENDED

QUESTIONS

1. Explain what is meant by the term *reflex response.*
2. Explain why reflex responses are important for survival.
3. EXTENDED With examples, distinguish between a voluntary and an involuntary reaction.

End of topic checklist

Key words

central nervous system, effector, involuntary, motor neurone, nerve, neurone, peripheral nervous system, reflex, reflex arc, relay neurone, sensory neurone, stimulus, voluntary

During your study of this topic you should have learned:

○ Plants and animals detect stimuli (changes in their surroundings) and respond to them.

○ A co-ordinated response requires a stimulus that is sensed by receptor cells, which results in a change in the organism brought about by an effector (usually muscles or glands in an animal).

○ The central nervous system consists of the brain and spinal cord, which co-ordinate and control responses.

○ Stimulation of receptor cells in sense organs causes electrical impulses to travel along nerves to the central nervous system.

○ The simple reflex arc is the connection of sensory neurone, relay neurone and motor neurone, which allows rapid responses without thinking.

○ **EXTENDED** Voluntary reactions are ones that we think about and can change; involuntary reactions are automatic responses, and often involve a reflex arc.

End of topic questions

Note: The marks given for these questions indicate the level of detail required in the answers. In the examination, the number of marks given to questions like these may be different.

1. Using the terms *stimulus*, *neurone*, *reflex arc*, *effector* and *response*, describe the response of someone who touches something very hot. **(5 marks)**

2. a) Describe the sequence of sensing and response in the nervous system of one of Andy Murray's opponents who returns a serve successfully. **(4 marks)**

b) Is this a reflex action? Explain your answer. **(2 marks)**

Δ Fig. 9.6 These are the cells that make up the retina; they are able to detect light and send messages to our brain.

EXTENDED

Sense organs

INTRODUCTION

Our senses allow us to detect changes in the environment, so that our body can respond to them.

We have five organs adapted to sensing changes in the environment – skin, tongue, nose, eyes and ears. All of them contain receptors that turn a stimulus in a message which is carried to our central nervous system

KNOWLEDGE CHECK

✓ Plants and animals detect the environment with specialised sense organs.

LEARNING OBJECTIVES

- ✓ **EXTENDED** Identify the structures of the eye and describe the functions of each.
- ✓ **EXTENDED** Explain the pupil reflex.
- ✓ **EXTENDED** Explain accommodation in the eye to near and distant objects.

HUMAN SENSE ORGANS

Different sense organs contain different specialised receptor cells that respond to different stimuli. Table 9.1 shows the different sense organs in humans.

Sense organ	Sense	Stimulus
skin	touch	pressure, pain, hot/cold temperatures
tongue	taste (chemicals)	chemicals in food and drink
nose	smell (chemicals)	chemicals in the air
eyes	sight	light
ears	hearing	sound
	balance	movement/position of head

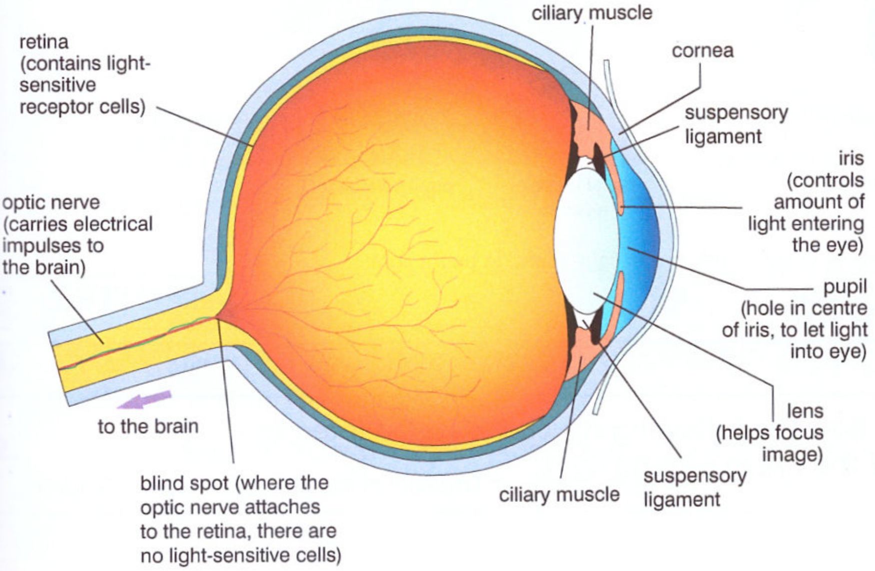
Δ Table 9.1 Human sense organs and their responses.

The eye

In humans, the eye is the sense organ that responds to changes in light. The specialised light-sensitive receptor cells are the cells of the retina at the back of the eye. Different light receptors are sensitive to different wavelengths of light, which is why we can see in colour.

Light passing through the eye and reaching the light-sensitive cells causes changes in these cells, which result in electrical impulses being sent to the brain along the optic nerve. Other structures of the eye have adaptations that support this process.

- The **cornea** and **lens** are transparent, to let light pass through without interference. Both structures also focus the light as it enters the eye, so that a focused image falls on the retina.
- The **pupil** is a hole that lets light through into the eye.
- The jelly inside the eye maintains the shape of the eyeball, so that the distance from front to back of the eye (the focusing distance) does not change.
- The **retina** is very dark, to absorb as much of the light that enters the eyes as possible.
- The **optic nerve** carries electrical impulses from the retina to the brain.


ciliary muscle
retina (contains light-sensitive receptor cells)
cornea
suspensory ligament
iris (controls amount of light entering the eye)
optic nerve (carries electrical impulses to the brain)
pupil (hole in centre of iris, to let light into eye)
lens (helps focus image)
to the brain
blind spot (where the optic nerve attaches to the retina, there are no light-sensitive cells)
ciliary muscle
suspensory ligament

Δ Fig. 9.7 Structure of the human eye.

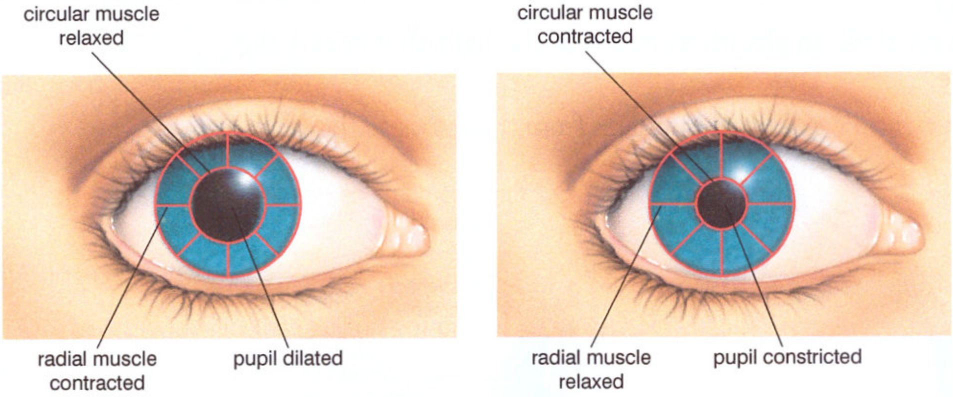
Where the neurones of the optic nerve connect with the light-sensitive cells, there is an area on the retina where there are no light-sensitive cells. This area cannot respond to light and is known as the blind spot.

The pupil reflex

The light-sensitive cells in the retina only respond to the stimulus of light above a certain light intensity. When it is so dark that the cells are not stimulated, we cannot see. As vision is an important sense to us, at low light intensities our eyes need to gather as much light as possible. So the pupil opens wider to allow more light to reach the retina.

However, the light-sensitive cells in the retina are easily and permanently damaged by high light intensity (which is why you should *never* look directly at a bright light source such as the Sun). So, to help protect the cells in the retina, the pupil responds in bright light by becoming smaller. This automatic response is called the pupil reflex.

The iris (the ring-shaped, coloured part of the eye) controls the amount of light entering the eye by adjusting the size of the hole in the centre, the pupil. The iris contains circular and radial muscles, which have an antagonistic action. This means the contraction of one set of muscles causes the relaxation and extension of the other set of muscles.
In bright light the circular muscles contract and the radial muscles relax, making the pupil smaller. This reduces the amount of light entering the eye, to avoid damage to the light-sensitive cells of the retina. The reverse happens in dim light, when the eye has to collect as much light as possible to see clearly.



△ Fig. 9.8 The pupil reflex response to light. Left: in dim light. Right: in bright light.

QUESTIONS

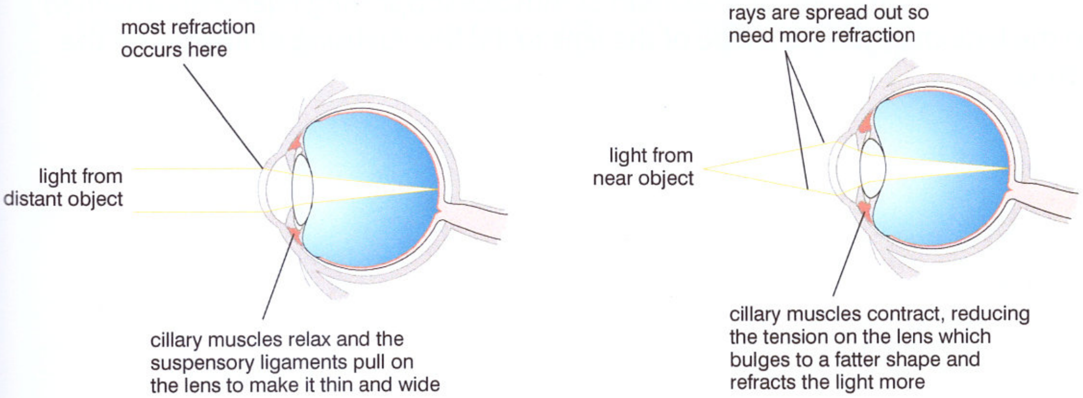
1. **EXTENDED** Explain how the following structures are adapted to support the role of the eye in sensing light:
   - **a)** cornea
   - **b)** pupil
   - **c)** retina.
2. **EXTENDED** Explain how the eye responds to changing light intensity.

Accommodation

In order to see clear images of our surroundings, the light that enters our eyes needs to be focused properly on the retina. The thick clear cornea bends light rays as they enter the eye in order to bring them to a focus on the retina. The lens provides fine focus to sharpen the image.

Adjustment of the fine focusing is needed to focus clearly on objects that are far away or near to us. This adjustment is called **accommodation**. Rays of light from distant objects are almost parallel when they enter the eye. They require less refraction (bending) to come to a focus on the retina and the cornea can manage most of this without help from the lens. The ciliary muscles relax and the lens is pulled into a thinner shape by the suspensory ligaments. This helps to focus the image clearly on the retina.

Rays of light from near objects are diverging when they enter the eye. They need much more powerful refraction to bend them to a focus on the retina. The ciliary muscles contract, which means they pull less on the suspensory ligaments. This allows the lens to form a more rounded shape. This refracts light more to achieve a focused image on the retina.


most refraction occurs here
light from distant object
cillary muscles relax and the suspensory ligaments pull on the lens to make it thin and wide
rays are spread out so need more refraction
light from near object
cillary muscles contract, reducing the tension on the lens which bulges to a fatter shape and refracts the light more

Δ Fig. 9.9 How the eye focuses light from (left) distant and (right) near objects.

QUESTIONS

1. EXTENDED Describe how the eye produces a focused image of an object that is near to the observer.
2. EXTENDED Explain how the eye adjusts to produce a focused image of an object that is distant to the observer.

END OF EXTENDED

End of topic checklist

Key words

accomodation, cornea, lens, optic nerve, pupil, retina, sense organ

During your study of this topic you should have learned:

○ The eye has many adaptations for its function in receiving light, including the light-sensitive cells in the retina, and the cornea and lens for focusing light.

○ EXTENDED Constriction or dilation of the pupil in response to changes in light intensity controls the amount of light entering the eye.

○ EXTENDED Contraction or relaxation of muscles supporting ligaments attached to the lens changes the shape of the lens to aid fine focusing of images on the retina.

End of topic questions

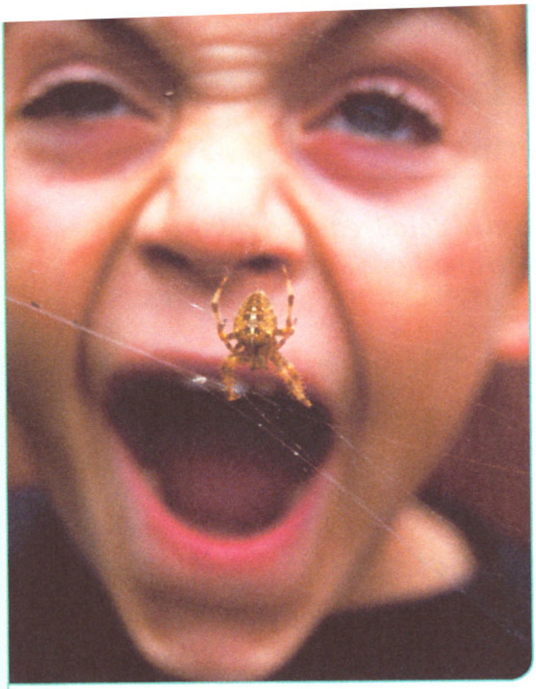
Note: The marks given for these questions indicate the level of detail required in the answers. In the examination, the number of marks given to questions like these may be different.

1. Explain the following.

a) A student visiting an underground mine couldn't see anything in the mine when the lights were turned off. **(1 mark)**

b) A cataract is a clouded lens in the eye, caused by many conditions. A patient with cataracts cannot see clear images. **(2 marks)**

c) **EXTENDED** A person who is long-sighted needs to wear spectacles with converging lenses in order to read something near to them. **(2 marks)**



Δ Fig. 9.10 Adrenaline is a hormone released when we are scared, which prepares our body for fight or flight.

Hormones

INTRODUCTION

Hormones are the chemical messengers of the body. Like the nervous system, they send messages around the body. In general, hormone messages tend to act more slowly and last longer than nervous messages.

They are responsible for many responses such as changes during puberty, responding to fear and maintaining the sugar balance of the blood.

KNOWLEDGE CHECK

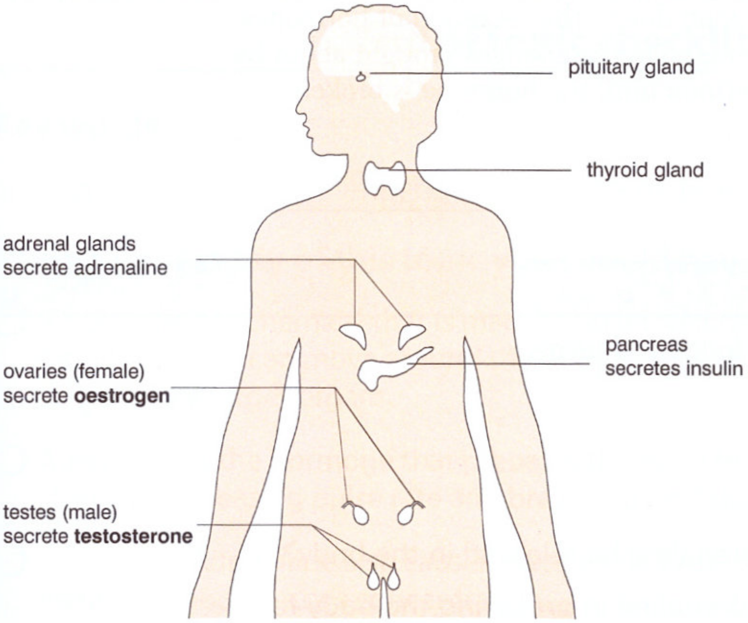
- ✓ Hormones are one of the ways that the body can send messages.
- ✓ Hormones help to control many processes in the body like puberty.

LEARNING OBJECTIVES

- ✓ Define a *hormone* as a chemical substance, produced by a gland and carried by the blood, which alters the activity of one or more specific target organs.
- ✓ Describe the hormone adrenaline and its effects.
- ✓ Give examples of situations in which adrenaline secretion increases.
- ✓ **EXTENDED** Discuss the role of the hormone adrenaline in the chemical control of metabolic activity.
- ✓ **EXTENDED** Compare nervous and hormonal control systems in terms of speed and longevity of action.

HORMONES IN HUMANS

Hormones are chemical substances used in the **hormonal system**. They are produced in **endocrine glands**. Endocrine glands do not have ducts (tubes) to carry away the hormones they make: the hormones are secreted directly into the blood to be carried around the body dissolved in the blood plasma. Hormones change the activity of other specific parts of the body, called the **target organs**. Most hormones affect several target organs; others may only affect one target organ.


pituitary gland
thyroid gland
adrenal glands secrete adrenaline
pancreas secretes insulin
ovaries (female) secrete **oestrogen**
testes (male) secrete **testosterone**

Δ Fig. 9.11 The position of some endocrine glands in the human body and the hormones they secrete.

Adrenaline

Adrenaline is a hormone that is produced in the adrenal glands just above the kidneys. This hormone is released in the crucial moments when an animal must instantly decide whether to attack or run for its life. This is often called the fight/flight response.

Some of the effects of adrenaline are:

- increased pulse (heart) rate to circulate blood more rapidly around the body, and deliver glucose and oxygen to muscle cells to allow more rapid contraction
- increased depth of breathing and breathing rate to take more oxygen into the body and remove carbon dioxide more rapidly from the body
- dilated pupils for better vision.

All these changes prepare the body for action.

EXTENDED

Adrenaline also causes liver and muscle cells to release glucose, which increases blood-glucose concentration. This means that there is more glucose available for increased muscle cell respiration, which will release more energy for muscle contraction.

Comparison of the nervous and hormonal systems

Changes in the body caused by the nervous system are usually produced rapidly, such as in a reflex response, and only last for a short time. This enables the body to respond quickly to rapid changes in the environment, such as blinking when a fly approaches your eye.

The changes in the body that happen due to the secretion of hormones are usually slower and longer lasting than the changes brought about by the nervous system, and may continue until the hormone is broken down by liver cells.

END OF EXTENDED

QUESTIONS

1. Explain the meaning of the following terms:
   a) *hormone*
   b) *endocrine gland*
   c) *target organ*.
2. In what conditions might adrenaline be released in the body?
3. Explain the advantages of adrenaline in preparing the body for action.
4. EXTENDED Compare the actions and effects of the nervous system and hormonal system in terms of the way in which they are brought about, the speed of response and their duration.

End of topic checklist

Key words

adrenaline, endocrine gland, hormonal system, hormone, insulin, target organ

During your study of this topic you should have learned:

○ A hormone is a chemical that is made in an endocrine gland, secreted into the blood so that it can move around the body, and controls the activity of cells in one or more target organs.

○ Adrenaline is the hormone that prepares the body for action or flight at times of stress, by increasing pulse rate and breathing, and dilating the pupils.

○ **EXTENDED** Adrenaline also causes muscle and liver cells to release glucose, and so increase blood-glucose concentration.

○ **EXTENDED** Rapid responses in humans are co-ordinated through nervous impulses in the nervous system, and longer-term responses are co-ordinated through chemicals (hormones) in the hormonal system.

End of topic questions

Note: The marks given for these questions indicate the level of detail required in the answers. In the examination, the number of marks given to questions like these may be different.

1. Using adrenaline as an example describe:

a) where it is made **(1 mark)**

b) one of the target organs it affects **(1 mark)**

c) the responses it brings about. **(3 marks)**

2. Explain why the release of glucose by adrenaline helps in the fight/flight response. **(3 marks)**

Δ Fig. 9.12 Our ability to maintain our body temperature allows us to live in places that are colder than body temperature.

Homeostasis

INTRODUCTION

Homeostasis is one of the functions of life: it enables organisms to maintain a constant internal environment.

Without homeostasis, we couldn't live in such a range of temperatures, because we wouldn't be able to maintain our body temperature. Responses like increasing metabolism and shivering help our bodies to generate heat when we get cold. If we get too hot, we can sweat to help us to cool down.

KNOWLEDGE CHECK

- ✓ Animals respond to changes in the environment using nervous and hormonal systems.
- ✓ Homeostasis helps keep the body temperature stable.

LEARNING OBJECTIVES

- ✓ Define *homeostasis* as the maintenance of a constant internal environment.
- ✓ Name and identify on a diagram the structures of the skin that respond to changes in body temperature.
- ✓ **EXTENDED** Explain that homeostais is the control of internal conditions within set limits.
- ✓ **EXTENDED** Explain control by *negative feedback*.
- ✓ **EXTENDED** Describe the control of the glucose content of the blood by the liver, and the roles of insulin and glucagon from the pancreas.
- ✓ Describe the maintenance of a constant internal body temperature in humans in terms of insulation, sweating, shivering and the role of the brain.
- ✓ **EXTENDED** Describe the maintenance of a constant internal body temperature in humans in terms of vasodilation and vasoconstriction of arterioles supplying skin surface capillaries.

HOMEOSTASIS IN HUMANS

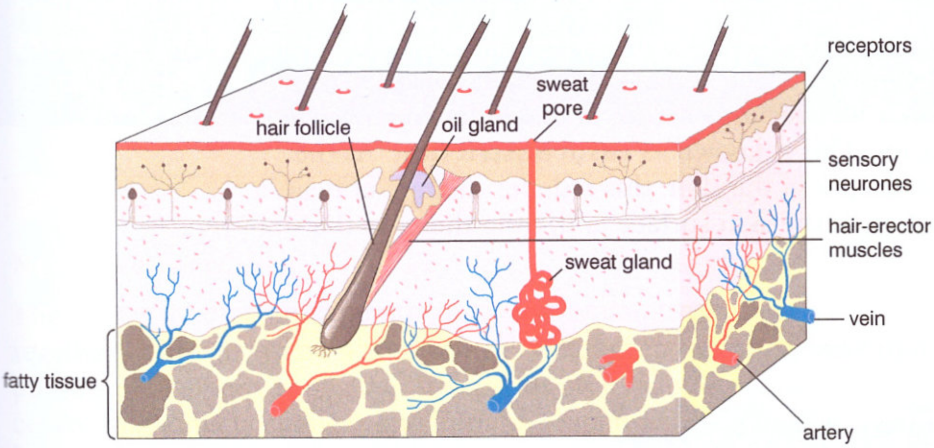
For our cells to carry out all the life processes properly, they need the conditions in and around them, such as the temperature and amount of water and other substances, to stay relatively constant. Keeping the internal environment constant is called **homeostasis**.

Temperature control

Homeostasis is the control of internal conditions within set limits. Staying within these limits helps the processes in the body to work most effectively. For example, as you saw in Topic 4, enzymes and the processes they control work best at an optimum temperature.

The temperature in the core (middle) of your body is about 37 °C, regardless of how hot or cold you may feel on the outside. This **core temperature** may naturally vary a little, but it never varies a lot unless you are ill.

Energy is constantly being released by cells as a result of respiration and other chemical reactions in the body, and is transferred to the surroundings outside the body. To maintain a constant body temperature, these two processes have to balance. The temperature of the blood from the core of the body is monitored by the hypothalamus in the brain. If the temperature varies too much from 37 °C, the hypothalamus causes changes to happen that result in the temperature returning to about 37 °C. The hypothalamus also receives electrical impulses from heat-receptor cells in the skin surface.



Δ Fig. 9.13 The structure of skin.

If core temperature rises too far, the following events occur.

- Sweat is released on to the surface of the skin from glands. Sweat is mostly water, and this water evaporates. Evaporation needs energy, so energy is removed from the skin surface as the sweat evaporates, cooling the skin.

EXTENDED

- Arterioles carrying blood near the surface of the skin dilate (get wider) so more blood flows through the capillaries in the skin. This is known as **vasodilation**, and is what makes you look pink when you are hot. This makes it easier for heat energy to be transferred to the skin surface and, from there, to the environment by radiation and conduction.

END OF EXTENDED

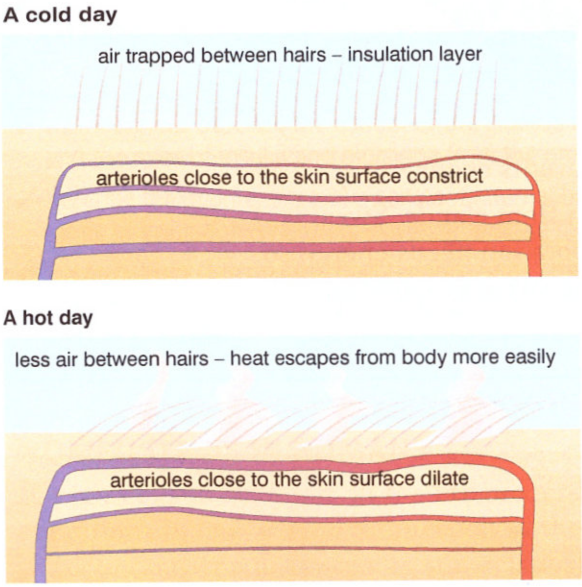
If core temperature falls too far, the following events occur.

- Body hair may be raised by muscles in the skin. This has little effect in humans (often called 'goose bumps') but is more effective in mammals with fur and in birds, because the fur or feathers trap air next to the skin. Air is not a good conductor of heat energy, so this still layer of air acts as insulation.
- Muscles may start to 'shiver'. This means that they produce rapid, small contractions. Cellular respiration is used to produce these contractions, releasing energy at the same time, which warms the blood flowing through the muscles.

EXTENDED

- Arterioles carrying blood near the surface of the skin constrict (get narrower), which reduces the amount of blood flowing through the surface capillaries. This is known as **vasoconstriction**. As the warm blood is kept deeper in the skin, this reduces the rate of heat transfer by conduction to the skin surface and, from there, to the environment.

END OF EXTENDED


A cold day
air trapped between hairs – insulation layer
arterioles close to the skin surface constrict
A hot day
less air between hairs – heat escapes from body more easily
arterioles close to the skin surface dilate

Δ Fig. 9.14 Arterioles respond to outside temperature.

Developing investigative skills

We can use a test tube of warm water wrapped in a wet paper towel as a model to investigate whether sweating really does cool the body, measuring how the temperature of the water changes over time.

Devise and plan investigations

❶ Explain how the tube models sweating in a human.

❷ How would you set up the control for this investigation? Explain your answer.

Make observations and measurements

The table shows the results of an investigation like the one described above.

	Time (min)	0	2	4	6	8	10	12	14	16
Temperature of water in tube (°C)	wet towel	56	50	46	42	39	36	34	32	31
	dry towel	56	52	49	46	44	44	41	40	39

❸ Use the results to draw a suitable graph.

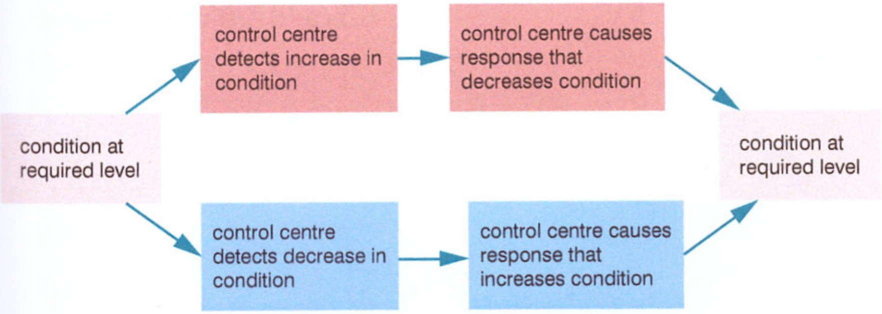
Analyse and interpret data

❹ Draw a conclusion from the graph, and explain the conclusion using your scientific knowledge.

EXTENDED

Negative feedback

The control of core body temperature is an example of **negative feedback**. This is where a change in a stimulus causes a response that produces the opposite change. It depends on a monitoring control centre that detects changes and initiates responses, such as the hypothalamus in the brain. We can summarise a negative-feedback response in a diagram like that shown in Fig. 9.15.


control centre detects increase in condition
control centre causes response that decreases condition
condition at required level
condition at required level
control centre detects decrease in condition
control centre causes response that increases condition

Δ Fig. 9.15 Negative-feedback response.

Homeostasis is the control of internal conditions within set limits. The effect of a negative-feedback response is to prevent large increases or decreases from the best condition for the body. This is how the temperature and pH of the tissues is controlled, so that enzymes work most effectively.

Control of blood-glucose concentration

It is important that the blood-glucose concentration remains within a small range. If it rises or falls too much you can become very ill very quickly.

After a meal, the blood-glucose concentration rises rapidly as glucose from digested food is absorbed from the small intestine. Cells in the pancreas detect this increase and respond by releasing the hormone **insulin**, which travels in the blood to the liver. Here, it causes any excess glucose to be converted to another carbohydrate, glycogen, which is insoluble and is stored in the liver.

Between meals, glucose in the blood is constantly diffusing into cells for use in cellular respiration. So the blood-glucose concentration falls. When a low level of glucose is detected by the pancreas, the insulin-secreting cells stop secreting insulin and other cells start to secrete the hormone glucagon instead. Glucagon converts some of the stored glycogen back into glucose, which is released into the blood to raise the blood-glucose concentration again.

END OF EXTENDED

QUESTIONS

1. Define the term *homeostasis* in your own words.
2. Give one example of homeostasis in the human body.
3. Explain the role of skin blood vessels in maintaining core body temperature.
4. EXTENDED Define the term *negative feedback*.
5. EXTENDED Use a negative-feedback diagram like the one in Fig. 9.15 to show how blood-glucose concentration is kept within a safe range.

End of topic checklist

Key words

core temperature, homeostasis, negative feedback, vasoconstriction, vasodilation

During your study of this topic you should have learned:

○ Homeostasis is the control of the internal environment of the body within narrow limits so that cells can function properly.

○ Core body temperature is monitored and regulated by the hypothalamus in the brain.

○ If the body is too hot, sweating helps to reduce body temperature. If the body is too cold, shivering helps to increase core temperature.

○ **EXTENDED** Vasodilation is the widening of blood vessels near the skin surface, which increases blood flow near the surface and increases the rate of loss of heat energy from the skin.

○ **EXTENDED** Vasoconstriction is the narrowing of blood vessels near the skin surface, which reduces blood flow and reduces the rate of heat loss from the skin.

○ **EXTENDED** Negative feedback occurs when a change in a stimulus results in a response that causes the opposite change to occur, and so maintain a steady state for a condition, such as core body temperature.

○ **EXTENDED** Insulin is the hormone made in the pancreas that reduces blood-glucose concentration when it is too high, by making muscle and liver cells take up glucose from the blood and convert it to glycogen.

○ **EXTENDED** Glucagon is the hormone made in the pancreas that increases blood-glucose concentration, by making liver cells break down glycogen to glucose and release it into the blood.

End of topic questions

Note: The marks given for these questions indicate the level of detail required in the answers. In the examination, the number of marks given to questions like these may be different.

1. One example of homeostasis in humans is the control of core body temperature.

a) Identify the receptors, monitoring area, and effectors in the response to a change in external temperature. **(3 marks)**

b) Describe the changes in the effectors if core body temperature is too high. **(1 mark)**

c) Describe the changes in the effectors if core body temperature is too low. **(2 marks)**

d) EXTENDED Explain why the changes that occur in the body when it is too hot help to return the core body temperature to normal. **(2 marks)**

2. EXTENDED Using the example of blood-glucose concentration, explain why negative-feedback control is an essential feature of homeostasis. **(3 marks)**

Tropic responses

INTRODUCTION

Plants also respond to changes in the environment. Two of the main responses they have are gravitropism – responding to gravity, and phototropism – responding to light. On the International Space Station, scientists explore how plants response to changes in gravity.

Δ Fig. 9.16 This plant is being grown in the International Space Station. It is important for scientists to understand tropisms, if they want to be able to grow plants in space.

KNOWLEDGE CHECK

✓ Plants respond to changes in the environment, such as by growth.

LEARNING OBJECTIVES

✓ Define *gravitropism* as a response in which parts of a plant grow toward or away from gravity.

✓ Define *phototropism* as a response in which parts of a plant grow toward or away from directional light.

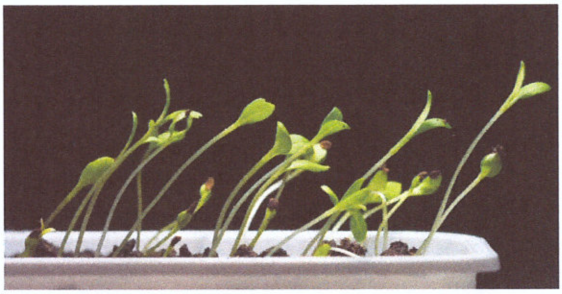
✓ Investigate gravitropism and phototropism in shoots and roots.

✓ **EXTENDED** Explain phototropism and gravitropism of a shoot as examples of the chemical control of plant growth.

✓ **EXTENDED** Explain the role of auxin in controlling shoot growth.

RESPONSES IN PLANTS

Plants generally respond to changes in the environment by a change in the way that they are growing. For example, a shoot will grow toward light, and in the opposite direction to the force of gravity, whereas a root will grow away from light, but toward moisture and in the direction of the force of gravity. These growth responses to a stimulus in plants are called **tropisms**. They help the plant to produce leaves where there is the most light, and roots that can supply the water that the plant needs.

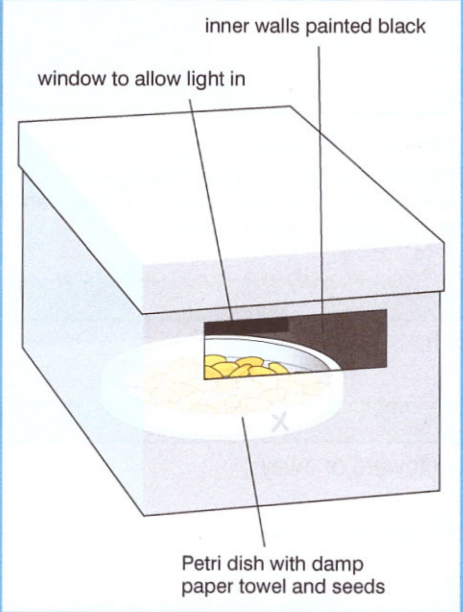


Δ Fig. 9.17 Growing toward light helps a plant get more light for photosynthesis.

- Growth in response to the direction of light is called **phototropism**. If the growth is toward light, it is called *positive* phototropism, as occurs in shoots. If the growth is away from light, it is called *negative* phototropism, as occurs in roots.
- Growth in response to gravity is called **gravitropism** (sometimes also called *geotropism*). Plant shoots show negative gravitropism, and plant roots show positive gravitropism.

Developing investigative skills

Figure 9.18 shows apparatus that can be used to investigate the effect of light on the growth of seedlings.


inner walls painted black
window to allow light in
Petri dish with damp paper towel and seeds

Δ Fig. 9.18 Apparatus for investigating the effect of light on the growth of seedlings.

Devise and plan investigations

❶ Explain how the apparatus could be used for this investigation.

❷ Explain how you would set up a control for this investigation.

Make observations and measurements

❸ If this investigation were set up correctly, what result would you expect to see in the seedlings from the windowed box, compared with your control? Explain your answer.

Evaluate data and methods

❹ Suggest how this investigation could be extended to investigate whether roots also show a phototropic response.

Control of tropic responses

Tropisms are controlled by plant hormones called **auxins**. Auxin is made in the tips of shoots and roots. It dissolves in water in the cells and diffuses away from the tip. Further back along a shoot, auxin *stimulates* cells to elongate so that the shoot or root grows longer.

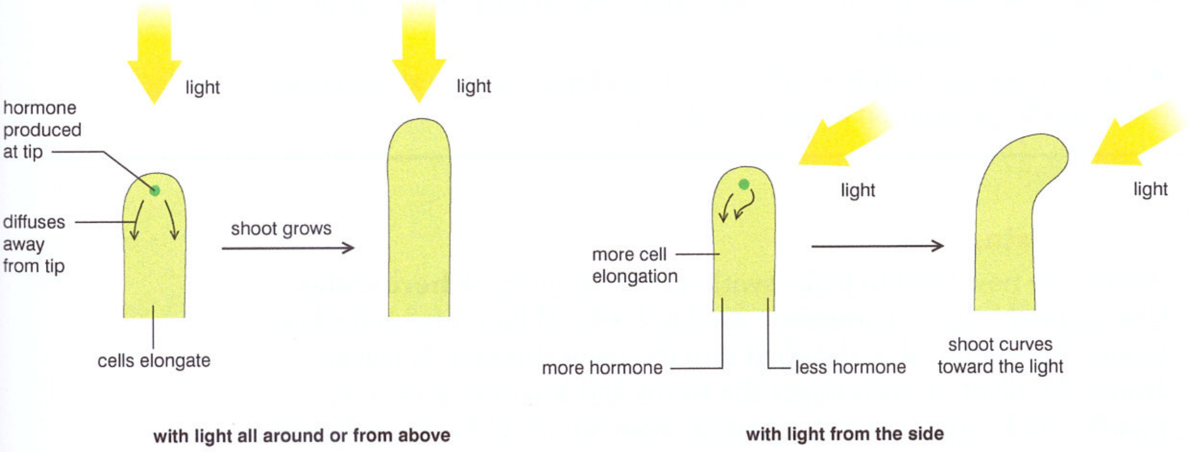
SCIENCE IN CONTEXT

GARDENER'S TIP

One effect of auxin is to inhibit the growth of side shoots. This is why a gardener who wants a plant to stop growing taller and to become more bushy will take off the shoot tip, so removing a source of auxin.

The growth of shoots toward light can be explained by the response of auxin to light.

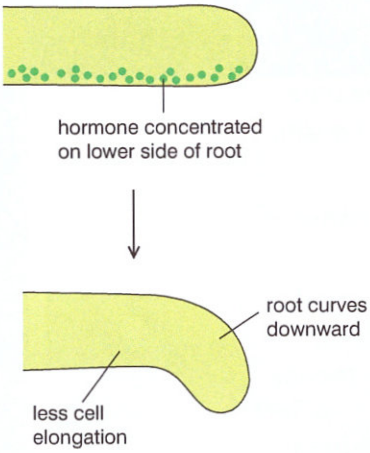
- When all sides of a shoot receive the same amount of light, equal amounts of auxin diffuse down all sides of the shoot. So cells all around the shoot are stimulated equally to grow longer. This means the shoot will grow straight up.
- When the light on the shoot comes mainly from the side, auxin on that side of the shoot appears to move across the shoot to the shaded side. The cells on the shaded side of the shoot will receive more auxin, and so grow longer than those on the bright side. This causes the shoot to curve as it grows, so that it grows toward the light.


light
hormone produced at tip
diffuses away from tip
cells elongate
shoot grows
light
with light all around or from above
light
more cell elongation
more hormone
less hormone
light
shoot curves toward the light
with light from the side

∆ Fig. 9.19 The effect of light on the growth of shoots.

In roots, auxin has the opposite effect on cells, so that it *reduces* how much the cells elongate.

- When roots are pointing straight downward, all sides of the root receive the same amount of auxin, so all cells elongate by the same amount.
- When the root is growing at an angle to the force of gravity, gravity causes the auxin to collect on the lower side. This reduces the amount of elongation of cells on the lower side of the root, so that the root starts to curve as it grows until it is in line with the force of gravity.



Δ Fig. 9.20 The effect of gravity on the growth of roots.

REMEMBER

- A full understanding of the phototropic responses in stems is needed to gain higher marks.
- Auxin causes curvature in shoots by the elongation of existing cells, not by the production of more cells.

Using auxins

Auxins are now used to make synthetic weedkillers, or **herbicides**. One example that is commonly used is 2,4-D. When it is sprayed on plants, the chemical is absorbed into the plant through its leaves. Inside the plant, it encourages the stems and leaves to grow very rapidly. Such large concentrations of auxin are used that growth is too fast, and the plant is unable to supply all the nutrients that the new cells need for healthy growth. Eventually the plant dies.

The advantage of using synthetic weedkillers like this is that grasses are unaffected by the herbicide, and only broad-leaved plants are killed. This is useful as many of our crop plants, such as wheat and maize, are grasses, and many of the weed plants that we want to clear from fields, so they don't complete with the crop plants, are broad-leaved plants.

END OF EXTENDED

QUESTIONS

1. Define the term *tropism* in your own words.
2. Give one example of:
   - a) positive phototropism
   - b) positive gravitropism.
3. **EXTENDED** Describe the action of auxin in a shoot growing in one-sided light.
4. **EXTENDED** Explain why auxins may be used as weedkillers.

End of topic checklist

Key words

auxin, gravitropism, phototropism, tropism

During your study of this topic you should have learned:

○ Plants respond to stimuli, often by growth responses called tropisms.

○ Plant shoots show positive phototropism when they grow toward light, and negative gravitropism as they grow away from gravity.

○ Plant roots show positive gravitropism when they grow toward the force of gravity, and negative phototropism when they grow away from light.

○ **EXTENDED** Auxins are plant growth hormones that control the responses of shoots and roots to light and gravity.

End of topic questions

Note: The marks given for these questions indicate the level of detail required in the answers. In the examination, the number of marks given to questions like these may be different.

1. Explain the survival advantage to plants of having:

a) shoots that are positively phototropic **(2 marks)**

b) roots that are positively gravitropic. **(2 marks)**

Scientists believe that there has been life on Earth for over 3500 million years. Nobody knows yet what triggered non-living molecules to become organised into living things that can reproduce themselves, but scientists have found traces of bacteria-like structures, which may represent the earliest forms of life, in very ancient rocks.

Reproduction leads to different combinations of characteristics in offspring, and mutation produces new characteristics. The environment in which early organisms lived determined which of these combinations of characteristics would be the most successful, and so which individuals were likely to survive and pass on those characteristics to their offspring through reproduction. This process led to the evolution of new species and eventually to the millions of species that are alive on Earth today.

CONTENTS

a) **Asexual and sexual reproduction**

b) Asexual reproduction

c) Sexual reproduction

d) **Sexual reproduction in plants**

e) Flowering plants

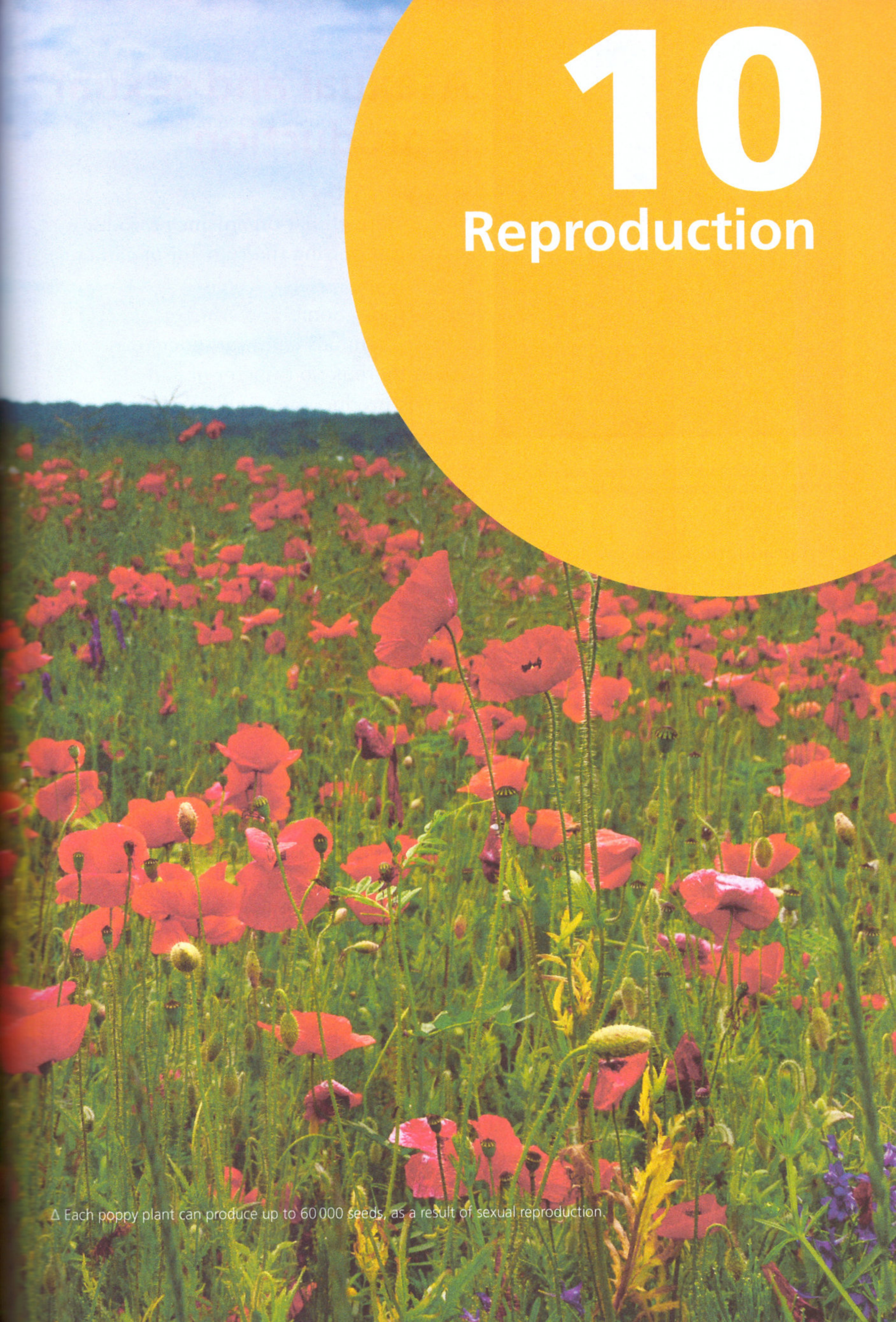
f) **Sexual reproduction in humans**

g) Human reproduction

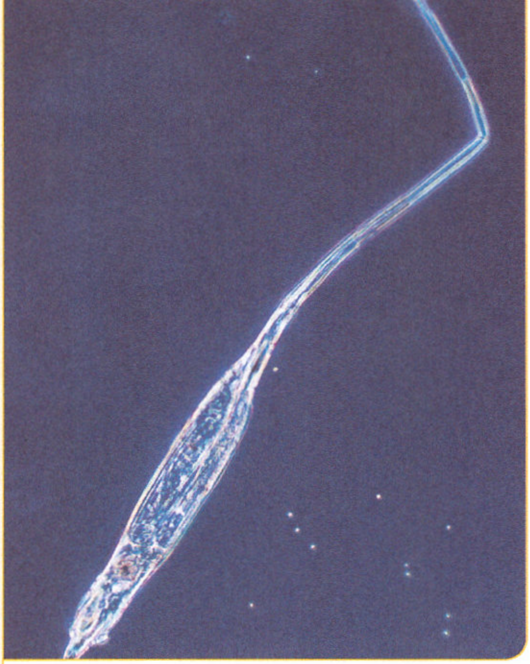
h) Sexually transmitted infections (STIs)

10

Reproduction



Δ Each poppy plant can produce up to 60 000 seeds, as a result of sexual reproduction.



Δ Fig. 10.1 Scientists think that this species of rotifer has not reproduced sexually for over 40 million years.

Asexual and sexual reproduction

INTRODUCTION

Most multicellular organisms reproduce sexually, requiring the transfer of gametes from the male to the female for fertilisation. Some flowering plants and a very few animals can reproduce asexually, where there is no transfer of gametes and females produce new individuals (more females) without fertilisation. Until recently, it was thought that asexual reproduction in animals was something that only happened as an addition to sexual reproduction. However, DNA evidence suggests that some species of stick insect have not reproduced sexually for over 1 million years. Males of these species don't exist.

KNOWLEDGE CHECK

- ✓ Sexual reproduction is the production of new individuals as a result of fertilisation; asexual reproduction is the production of new individuals without fertilisation.

LEARNING OBJECTIVES

- ✓ Define *asexual reproduction* and *sexual reproduction*.
- ✓ Identify examples of asexual reproduction from information provided.
- ✓ **EXTENDED** Describe the advantages and disadvantages of asexual and sexual reproduction to a population of species in the wild.
- ✓ **EXTENDED** State that the nuclei of gametes are haploid and that the nucleus of a zygote is diploid.

ASEXUAL REPRODUCTION

Some organisms increase in number by **asexual reproduction**. For this type of reproduction, it is not necessary to have two parents. During asexual reproduction, cells from an adult organism divide to produce the offspring. This means that offspring produced by asexual reproduction are genetically identical to their parent and to each other.

Asexual reproduction is used by many different organisms. Bacteria reproduce asexually using binary fission. When they are large enough, their genetic material copies itself exactly and then the cell splits in half. The process then begins all over again. This can occur very rapidly to produce large numbers of identical bacteria.

Δ Fig. 10.2 The toadstools we see growing are specialised spore-producing bodies of fungi.

Almost all fungi can reproduce asexually. Different types of fungi use different means of asexual reproduction, but by far the most important type is that of spore formation. This can be seen in *Mucor,* the common pin mould, which often grows on bread. When this fungus has a plentiful supply of nutrients a **hypha** grows up vertically and the tip swells with cytoplasm containing many nuclei. This tip releases many spores into the atmosphere. If they find the right conditions for growth, each spore can develop into a new **mycelium**.

Δ Fig. 10.3 Each of the potato tubers formed by this plant could produce a new plant in the next growing season.

Another form of asexual reproduction is seen in plants such as potatoes that produce tubers. Tubers form from the end of stems that grow underneath the soil surface. The stems swell into storage organs filled with starch. When the leaves and stems of the plant die back at the end of the growing season the tubers stay dormant until the next season. Each tuber then produces several potato plants from the buds on the side of the tuber. Each potato plant gives rise to several tubers and each tuber produces a number of plants, so several new plants are formed from one parent.

EXTENDED

Advantages and disadvantages

Asexual reproduction has advantages and disadvantages.

Advantages:

- Only one parent is required; there is no need for a parent animal to find a mate or for pollination in plants.
- Often large numbers of organisms can be produced in a relatively short time.
- All the offspring produced are identical, so should survive well in the conditions in which the parent grows.

Disadvantages:

- The lack of variation in the offspring means that any adverse change in conditions will affect all equally.
- Because the offspring do not vary, they are not suited to moving away and exploiting environments with different conditions.

END OF EXTENDED

REMEMBER

You must be able to apply your knowledge and identify as many differences between asexual and sexual reproduction as you can.

QUESTIONS

1. Define the term *asexual reproduction* in your own words.
2. Explain why binary fission of bacteria is an example of asexual reproduction.
3. EXTENDED Explain the advantages and disadvantages to a population of species in the wild of reproducing asexually.

SEXUAL REPRODUCTION

Sexual reproduction is the most common method of reproduction for the majority of larger organisms, including almost all animals and plants. It occurs when there is **fertilisation**, which is when the nucleus of a male **gamete** (sex cell) fuses with the nucleus of a female gamete to form a **zygote**. The zygote will contain some of the genetic information of each of its parents. So it will be genetically different from each of the parents. It will also be genetically different from all other offspring produced by those parents (unless it has an identical twin).

EXTENDED

Sexual reproduction involves **haploid** cells, which have just one set of genetic information, and **diploid** cells that have two sets of genetic information (see Topic 11). The gametes are the haploid cells, and when they fuse they produce a diploid cell, which is the zygote. The cell of the zygote will divide repeatedly to produce all the cells of the new organism, and all these cells will be diploid.

Advantages and disadvantages

There are advantages and disadvantages to sexual reproduction.

Advantages:

- Fusion of gametes brings genetic information from two parents, which results in variety in the offspring. This produces individuals that may be better adapted to different conditions than the parents and each other, which makes the chance of survival of the **species** in changing conditions more likely.

Disadvantages:

- Sexual reproduction usually requires a second parent for fertilisation. Finding a mate can take time and energy for the individual, and failure to mate means that the individual produces no offspring.
- The need to find a mate also means that sexual reproduction takes longer to produce offspring than asexual reproduction.

END OF EXTENDED

QUESTIONS

1. Define the following terms in your own words:

   a) *fertilisation*

   b) *sexual reproduction.*

2. EXTENDED Give an example of

   a) a haploid cell

   b) a diploid cell.

3. EXTENDED Describe an advantage and a disadvantage of sexual reproduction to a population of species in the wild.

End of topic checklist

Key words

asexual reproduction, diploid, fertilisation, gamete, haploid, sexual reproduction, zygote

During your study of this topic you should have learned:

- ○ How to define a sexual reproduction as the production of new individuals without fertilisation. It is the division of the body cells of one parent. It produces offspring that are genetically identical to the parent and to each other.
- ○ How to define sexual reproduction as the production of new individuals from the fusion of a male gamete and a female gamete during fertilisation. It requires two parents, and produces offspring that are genetically different to their parents and to each other.
- ○ That fertilisation of a male gamete and female gamete produces a zygote that develops into an embryo by cell division.

End of topic questions

Note: The marks given for these questions indicate the level of detail required in the answers. In the examination, the number of marks given to questions like these may be different.

1. For each statement, decide whether the example is linked to sexual reproduction or asexual reproduction

- All offspring are genetically identical
- The offspring have two parents
- Bacteria dividing into two using binary fission
- Spore formation in fungi
- Offspring show variation **(5 marks)**

2. Using the key words *fusion*, *gametes*, *nuclei* and *zygote*, explain how sexual reproduction gives rise to genetically different offspring. **(4 marks)**

End of topic questions continued

3. EXTENDED Aphids are common pests of crop plants. In countries where the climate is seasonal, they reproduce in different ways at different times of the year. During the summer, when there is a lot of food about, female aphids reproduce asexually. As it gets cooler towards winter and plants start to die back, winged males and females reproduce sexually. Fertilised eggs are laid that survive through the winter, and hatch into females in the spring.

   a) Describe and explain two features of reproducing asexually that allow aphids to be successful during the summer. **(4 marks)**

   b) Describe one feature of sexual reproduction that helps aphids to be successful in the following year. **(4 marks)**

Δ Fig. 10.4 The corpse flower smells like rotting corpses and attracts flies to pollinate the flowers.

Sexual reproduction in plants

INTRODUCTION

Sexual reproduction produces variety in plants, and so flowering plants are very adaptable and can be found across the Earth. Flowering plants are adapted to maximise pollination and this has given rise to a number of unusual structures.

KNOWLEDGE CHECK

✓ The flower is the reproductive structure in flowering plants.

LEARNING OBJECTIVES

✓ Identify, draw and label a diagram to show the sepals, petals, stamens, filaments and anthers, carpels, style, stigma, ovary and ovules of an insect-pollinated flower.
✓ State the functions of the sepals, petals, anthers, stigmas and ovaries.
✓ Name the agents of pollination.
✓ Define *pollination* of a flower as the transfer of pollen from an anther to a stigma.
✓ State that fertilisation occurs when a pollen nucleus fuses with a nucleus in an ovule.
✓ **EXTENDED** Use a hand lens to identify and describe the anthers and stigmas of a wind-pollinated flower.
✓ **EXTENDED** Distinguish between the pollen grains of insect-pollinated and wind-pollinated flowers.
✓ **EXTENDED** Describe the structural adaptations of insect-pollinated and wind-pollinated flowers.
✓ State and investigate the environmental conditions required for germination of seeds.

FLOWERING PLANTS

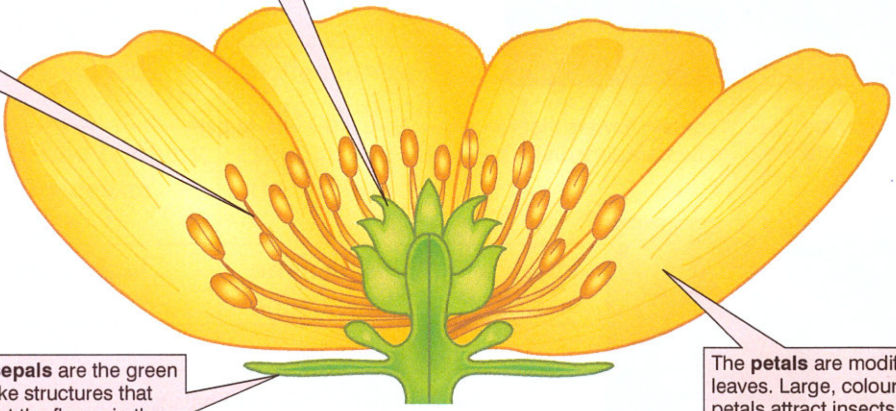
The most successful group of plants is the flowering plants. These are the only plants to have true flowers and produce **seeds** with a tough protective coat. During sexual reproduction in flowering plants:

- male and female gametes are produced – some species may produce male and female gametes in the same flowers; other species may have male-only flowers and female-only flowers on the same plant; and in other species male flowers and female flowers are produced on different plants
- male pollen is transferred to the female part of the flower so that **pollination** can take place

- the male gamete and female gamete fuse during fertilisation to form a zygote
- the zygote develops to form an embryo within a seed, which protects the embryo and provides food during germination of the seed
- seeds are dispersed, so that they germinate and grow away from the parent.

Structure of flowers

All flowers have a similar basic arrangement. They have structures stacked one on top of each other along a short stem, arranged either in a spiral or in separate rings.



The centre of the flower contains the female parts, which consist of the **carpels**, containing the **ovules** inside which are the female gametes.

The **stamens**, which contain **anthers**, are the male parts of the flower. The anthers contain cells that produce the male gametes (inside the pollen grains) as the flowers mature.

The **sepals** are the green leaf-like structures that protect the flower in the bud. They are the lowest ring of structures.

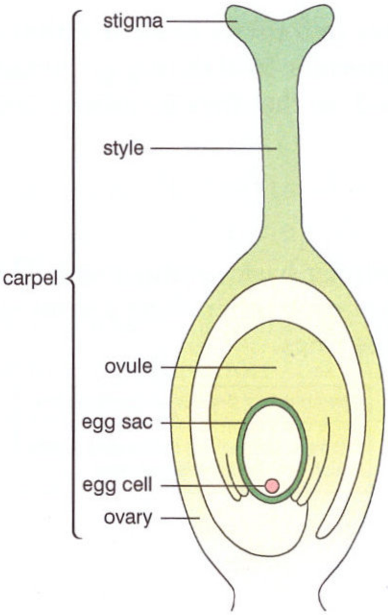
The **petals** are modified leaves. Large, colourful petals attract insects for pollination. Some petals are shaped to guide insects to particular parts of the flower.

∆ Fig. 10.5 Structure of an insect-pollinated flower.

The male part of a flower is the ring of **stamens**. There may be up to 100 stamens, or fewer than a dozen. Each stamen consists of two parts – the **anther** at the top and a stalk called the *filament*. Pollen grains develop inside the anthers. Inside each pollen grain is a male gamete. As a grain matures, it develops a thick outer wall to protect the delicate male gamete inside. When all the pollen grains in the anther are mature, the anther splits open to release them.

The female part of the flower is the **carpel**. A flower can contain more than one carpel, each with its own **style** and **stigma**. The **stigma** is the part of the carpel where the pollen lands during pollination. The **ovary** at the base of the carpel protects the female gamete from the dry air outside. The ovary contains one or more **ovules**, and each ovule contains an egg sac that surrounds the egg cell (female gamete).

Δ Fig. 10.6 Alder catkins contain flowers that shed pollen into the air to be transported to other flowers.



Δ Fig. 10.7 The carpel.

◁ Fig. 10.8 Even complex flowers like daisies, which contain thousands of male and female parts, have carpels surrounded by stamens.

QUESTIONS

1. Name the female parts of a flower, and describe the function of each part.
2. Name the male parts of a flower, and describe the function of each part.

Pollination

Before fertilisation can take place, the male gametes have to reach the female gametes. This involves transferring the pollen to the stigma, in a process known as *pollination*. In many plants, this means transferring the pollen from one flower to another. Some plants use the wind to transfer their pollen between flowers; others use animals, especially insects, to carry the pollen. Flowers have different features depending on whether they are pollinated by wind or by insects.

Wind-pollinated plants	Insect-pollinated plants
small petals, which do not obstruct pollen dispersal	large petals for insects to land on
green or inconspicuous petals	brightly coloured petals to attract insects
no scent	often scented to attract insects
no nectaries	nectaries present at the base of the flower produce a sugary liquid to attract insects, e.g. bees and butterflies
many anthers, which are often large and hang outside the flower so that pollen is easily dispersed	a few small anthers, usually held inside the flower
pollen grains have smooth outer walls	pollen grains have sticky or spiky outer walls
stigmas are large and feathery, often hanging outside the flower to trap pollen	stigmas are small and held inside the flower
produce large amounts of pollen	produce smaller amounts of pollen
pollen is lightweight	pollen is heavier

Δ Table 10.1 Comparison of wind-pollinated and insect-pollinated flowers.

Δ Fig. 10.9 In insect-pollinated plants, nectaries secrete a sugary liquid to attract insects.

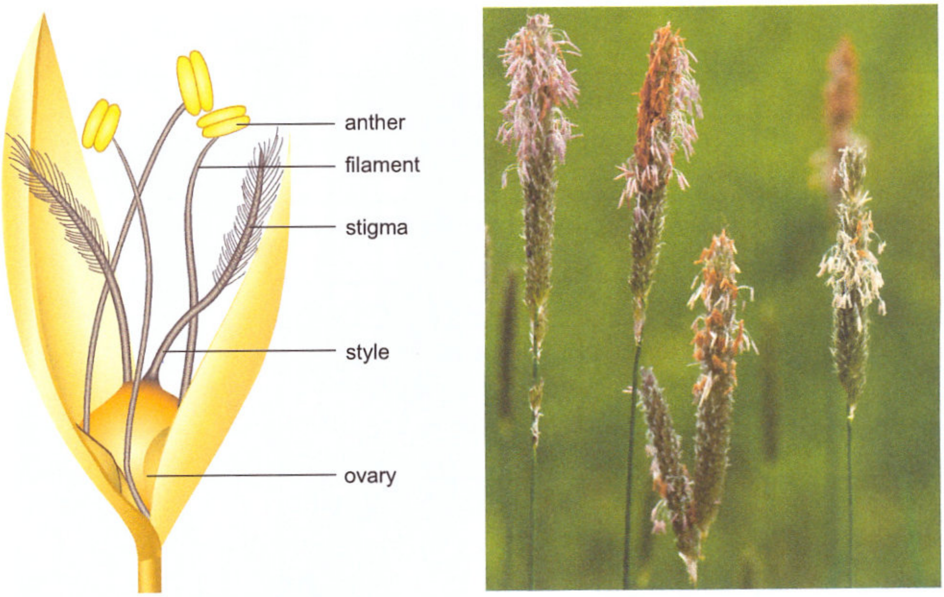
SCIENCE LINK

PHYSICS – PROPERTIES OF WAVES

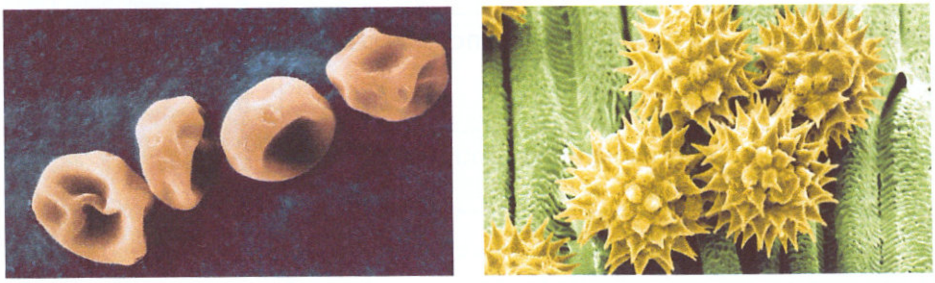
- Insects that transfer pollen often have eyes which are sensitive to different wavelengths of the electromagnetic spectrum in comparison to humans, so the colours of flowers are adapted to match this – flowers can appear very differently when viewed as insects view them.

PHYSICS – FORCES

- Several of the adaptations of pollen from wind-pollinated plants relate to forces and motion – shapes that reduce drag, masses that are easy to accelerate on the wind – and there are links to the motion of parachutes, for example.



Δ Fig. 10.10 These grass plants have anthers that hang outside the flowers and release large amounts of pollen to the wind. The stigmas also hang outside the flower to collect pollen from other grass plants.



Δ Fig. 10.11 Pollen grains. Left: from a wind-pollinated plant (birch) with a simple smooth outer wall. Right: from an insect-pollinated flower (daisy), with a spiky coat that helps the grains stick to the hairs on an insect's body.

SCIENCE IN CONTEXT

FLOWERS AND POLLINATORS

Different features of animal-pollinated flowers attract different pollinators. Tube-shaped flowers attract insects with a long tongue, such as butterflies, or birds with a long bill, such as hummingbirds. Blue and violet flowers are more attractive to bees, whereas butterflies often prefer red. Plants that are pollinated by moths or bats tend to open at night and may not be brightly coloured, but instead produce a strong sweet scent. Plants that rely on flies to pollinate them often smell like rotting flesh.

One of the most bizarre partnerships between flower and insect occurs between a particular species of orchid and a wasp. Male wasps are attracted to the flowers to mate with what they think are female wasps. During the 'mating', the flowers deposit pollen on the insect, which then carries it to the next flower that it is attracted to.

Δ Fig. 10.12 A male wasp receiving pollen while 'mating' with an orchid flower.

END OF EXTENDED

REMEMBER

Be very careful not to confuse *pollination* with *fertilisation*.

SCIENCE IN CONTEXT

THE PROBLEM WITH BEES

About a third of all plants that we use for food or other uses depend on bees for pollination. This includes plants such as oilseed rape, cotton, coffee, apples and pears. If there are few bees, the crop harvest can be reduced by up to 75%. During the flowering season of crop plants, farmers and growers may place bee hives close to the crop to encourage successful pollination of flowers. This helps to ensure a good harvest.

Δ Fig. 10.13 By encouraging bees to build their hives in portable boxes, the farmer can move the hives to where the flowers of a crop are ready for pollination.

Recently, people have become concerned about a large decrease in bee populations. There are many possible reasons for this. In some places, it has been suggested that the lack of a range of food plants, including weeds, has been the cause. An increase in the use of pesticides that also kill bees may be another cause of the fall in their numbers.

Without bees, food production will be greatly affected. So there are many studies being done to identify why bee numbers are decreasing and to work out how to improve the environment for bees.

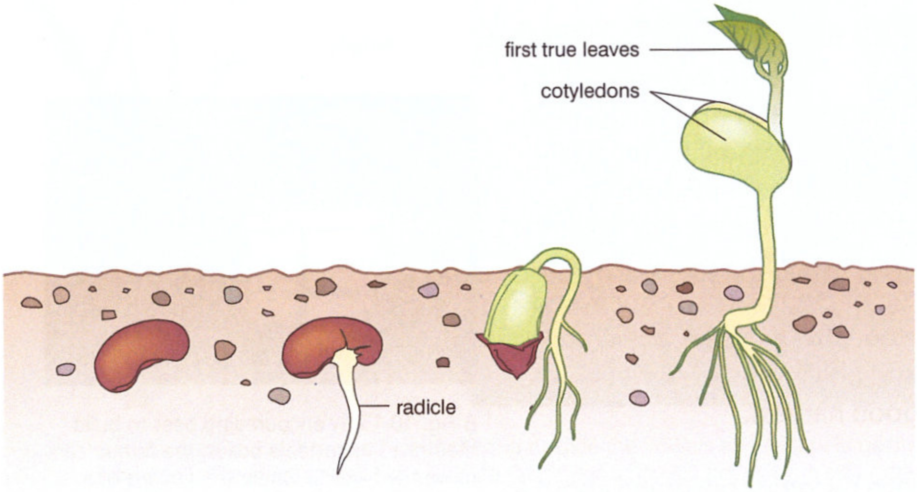
QUESTIONS

1. Distinguish between *pollination* and *fertilisation* in a plant.
2. EXTENDED Describe *three* differences in structure between wind-pollinated and insect-pollinated flowers.
3. EXTENDED **a)** Explain the advantage to a flower of having adaptations for attracting insects, rather than relying on wind for pollination.

   EXTENDED **b)** Describe one disadvantage for an insect-pollinated plant that relies on one or just a small number of insect species for pollination.

Germination

Germination is when the seed coat breaks open, and the embryo starts to grow and develop into a new plant.



Δ Fig. 10.14 Germination of a bean seed.

There are three environmental conditions that need to be right for seeds to germinate:

- temperature
- moisture
- oxygen.

The presence of light is not usually needed for germination. This is because most seeds germinate below ground, so they cannot get their food from photosynthesis.

Temperature

A seed will not start to germinate until the conditions around it reach a suitable temperature. Many seeds lie dormant for long a time during cold periods, such as winter, and start to grow as the earth warms. However, if the temperature becomes too hot, the seed may be killed. This is why it is very important to store seeds in the correct conditions and to control the temperature in glasshouses carefully, e.g. through the use of ventilation and shading.

SCIENCE IN CONTEXT

CONDITIONS FOR GERMINATION

Different plants are suited to different climates. Those that are adapted to colder climates will germinate at lower temperatures. They may also need a very cold period followed by an increase in temperature before they will germinate.

Other seeds will not germinate until they have been exposed to very high temperatures, such as the heat from a forest fire. The extreme heat weakens the seed coat so that water can enter the seed and germination can begin.

Δ Fig. 10.15 Fire clears the ground of competing plants, and stimulates these seeds to germinate in ideal conditions.

Germinating after a fire means that there is likely to be less competition with other species that usually cover the ground. Also, the ash left from the burning acts as a natural fertiliser for the new plants.

Water

Water is required to swell the seed and burst the seed coat. All seeds contain some moisture, but during germination metabolic reactions are carried out rapidly. More water is needed for:

- activation of hormones and enzymes
- hydrolysis of storage compounds, e.g. conversion of starch to glucose
- transport of materials to be used for respiration and growth
- metabolic reactions and enzyme actions that occur in solution.

Oxygen

Active living cells respire and the most useful form of respiration, aerobic respiration, requires oxygen. Seeds can use anaerobic respiration for a short while, but the rate at which energy is released is very slow (not useful in an actively growing organism) and the by-products are toxic. That is why most seeds will only germinate successfully if there is plenty of oxygen in the soil.

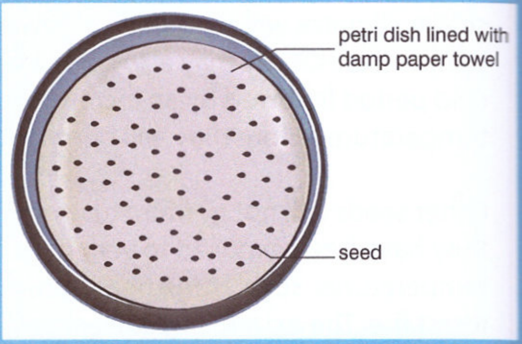
Δ Fig. 10.16 Waterlogged soil excludes oxygen, making it difficult for these seeds to germinate and grow.

Developing investigative skills

We can investigate the particular conditions for germination.

Devise and plan investigations

❶ Using the apparatus shown, write a plan to investigate the effect of (a) light, (b) water and (c) temperature on the germination of seeds. Think carefully about what controls to use in each case.



Δ Fig. 10.17 A simple set-up for investigating seed germination.

Make observations and measurements

An investigation was carried out using two petri dishes containing 20 seeds of the same species. Both dishes received the same amount of light and moisture, but they were kept at different temperatures. The table shows the number of seeds that germinated over a period of 8 days.

❷ Display the results of this investigation in a suitable way.

Day	Total number germinated seedlings	
	Cool/10 °C	Warm/20 °C
1	0	0
2	0	0
3	0	5
4	1	11
5	6	15
6	16	17
7	18	17
8	18	17

Analyse and interpret data

❸ Describe the patterns shown by these results.

❹ Draw a conclusion from these results.

❺ Explain the results using your scientific knowledge.

QUESTIONS

1. What is *germination*?
2. What effect do the following conditions have on germination of seed? Explain why they have these effects.
   a) oxygen
   b) moisture
   c) warmth

End of topic checklist

Key words

anther, carpel, germination, ovule, pollination, seed, stamen, stigma, style

During your study of this topic you should have learned:

○ How to identify the male and female parts of a flower.

○ Seeds need moisture, oxygen and warmth for successful germination.

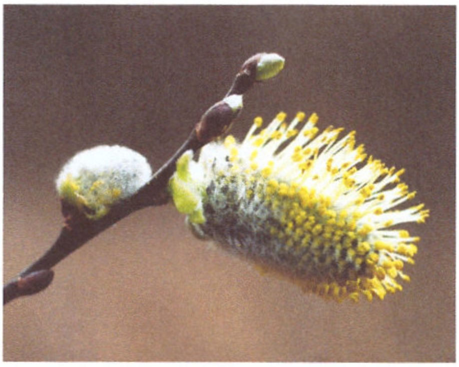
○ **EXTENDED** An insect-pollinated flower has features such as coloured petals, scent and nectaries to attract insects to feed at the flower. The insects pick up pollen, which they transfer to other flowers that they move on to.

○ **EXTENDED** A wind-pollinated flower is usually small, without colour, scent or nectaries. It produces a large amount of lightweight pollen, which is scattered over a large distance in the wind.

End of topic questions

Note: The marks given for these questions indicate the level of detail required in the answers. In the examination, the number of marks given to questions like these may be different.

1. The photograph in Fig. 10.18 shows a catkin on a goat willow tree. A catkin is formed from a group of flowers.



Δ Fig. 10.18 goat willow catkin.

a) What is the purpose of the flowers on a goat willow tree? **(1 mark)**

b) Name the yellow parts of the flowers shown in this photograph. **(1 mark)**

c) Describe their purpose in a flower. **(1 mark)**

d) Are goat willow flowers pollinated by the wind or by insects? Explain your answer using clues from the photograph. **(3 marks)**

2. a) Explain the advantage to a flower of having adaptations for attracting insects, rather than relying on wind for pollination. **(1 mark)**

b) Describe one disadvantage for an insect-pollinated plant of relying on one or just a small number of insect species for pollination. **(1 marks)**

3. EXTENDED In many flowers that have stamens and stigmas, the stamens mature and shed their pollen before the stigma matures and accepts pollen.

a) Describe and explain one advantage for the plant of doing this. **(2 marks)**

b) Describe and explain one disadvantage for the plant of doing this. **(2 marks)**

4. A gardener has some packets of seeds for planting. The packets explain how to plant the seeds to get the best germination.

a) What is meant by *germination*? **(1 mark)**

b) All the packets say that the seeds need to be planted in moist compost and kept warm. Explain why the seeds need these conditions. **(2 marks)**

c) Explain why the seeds will not germinate successfully in waterlogged soil. **(2 marks)**

d) The larger seeds need to be planted deeper in the compost, and the tiniest seeds need to be scattered on the surface of the compost. Explain why different seeds need to be planted at different depths. (Hint: think about food reserves.) **(3 marks)**

e) Some seeds that come from plants in high-latitude regions (such as Canada or Russia) need to be placed in the freezer for a few weeks before they will germinate. This makes them respond as if they had been through a cold winter. Explain the survival advantage of this adaptation. **(2 marks)**

Sexual reproduction in humans

△ Fig. 10.19 The miracle of life – a newborn has just been delivered, after a 9-month pregnancy.

INTRODUCTION

Like all mammals, humans reproduce sexually and have specially adapted reproduction systems. After puberty, males are fertile all of the time, producing sperm constantly. However, females are only fertile at the mid-point of their menstrual cycle, and normally only release one egg at a time.

KNOWLEDGE CHECK

✓ The human reproductive system consists of organs, tissues and cells that are specially adapted for their role in reproduction.

LEARNING OBJECTIVES

✓ Identify and name on diagrams the parts of the male and female human reproductive systems and describe their functions in reproduction.

✓ Describe fertilisation as the fusion of the nuclei from a male gamete (sperm) and the female gamete (egg cell/ovum).

✓ **EXTENDED** Compare male and female gametes in terms of size, structure, numbers and motility.

✓ **EXTENDED** State the adaptive features of sperm.

✓ **EXTENDED** State the adaptive features of egg cells.

✓ State that in early development, the zygote forms an embryo which is a ball of cells that implants into the wall of the uterus.

✓ Describe the changes in the uterus and ovaries during the menstrual cycle.

✓ **EXTENDED** State the functions of the umbilical cord, placenta, amniotic sac and amniotic fluid.

✓ **EXTENDED** Describe the function of the placenta and umbilical cord in relation to exchange of dissolved nutrients, gases and excretory products, and providing a barrier to toxins.

✓ State that human immunodeficiency virus (HIV) infection may lead to acquired immune deficiency syndrome (AIDS).

✓ Describe the methods of transmission of HIV.

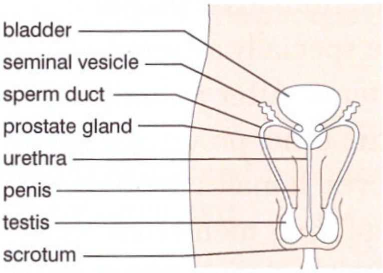
✓ Explain how the spread of sexually transmitted infections (STIs) is controlled.

HUMAN REPRODUCTION

Male reproductive system

A human male has two **testes** (singular: **testis**) in which **sperm** are produced. The testes are supported outside the body in the scrotum to keep them cooler, because at higher temperatures fewer sperm are produced.

Sperm ducts carry the sperm from the testes to the penis, through the prostate gland and seminal vesicles. The prostate gland and seminal vesicles together produce the liquid in which the sperm are able to swim. Semen is the mixture of sperm cells and fluids.



Δ Fig. 10.20 The male reproductive system. (Note that the bladder is not part of the reproductive system.)

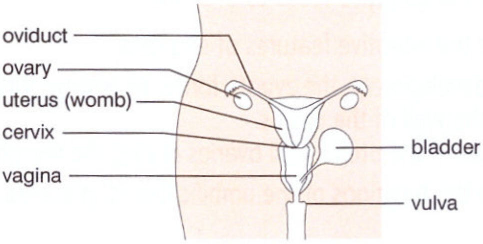
Semen passes along the sperm duct to the urethra, to outside the body. The urethra also carries urine from the **bladder** to outside the body. When the man is sexually excited, large spaces in the penis fill with blood. This causes the penis to become larger and stiffer, causing an erection. At the same time, a muscle ring (sphincter) at the top of the urethra contracts, preventing urine entering the urethra from the bladder.

The erection makes it possible for the man to insert his penis into the **vagina** of the woman for sexual intercourse. Rapid contractions of muscles in the penis during ejaculation send the sperm shooting out into the vagina.

Female reproductive system

The two **ovaries** are the organs in human females that produce the eggs. They are positioned within the abdominal cavity, either side of the **uterus** and joined to it by the **oviducts**.

Every month from puberty until menopause, when a woman is around 50 years old, one ovary usually releases one egg, which travels down the oviduct to the uterus (womb). If it is not fertilised, the egg will be flushed from the uterus during the monthly period (bleed).



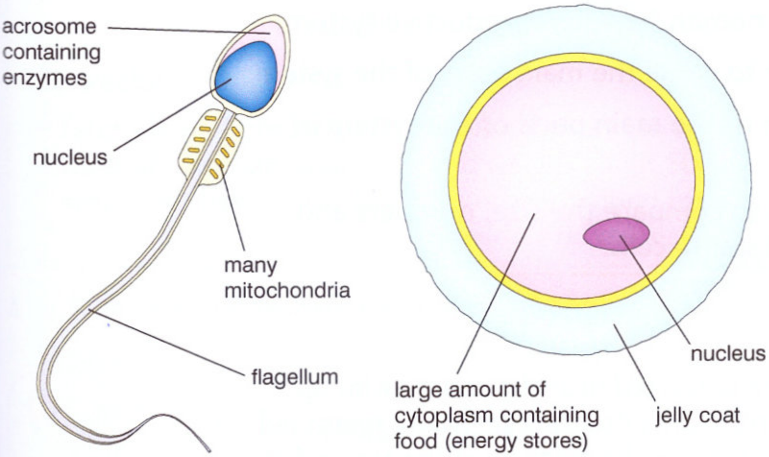
Δ Fig. 10.21 The female reproductive system. (Note that the bladder is not part of the reproductive system.)

At the lower end of the uterus is the **cervix**. This canal produces mucus which changes during the **menstrual cycle**, allowing sperm to pass through at some times and not others. It also keeps the developing baby secure in the uterus until birth. The cervix leads into the vagina. The **vagina** is an elastic muscular tube where sperm is received from the penis during sexual intercourse.

EXTENDED

Human gametes

The human gametes are specialised for their roles in reproduction (see Topic 2). The adaptive features of the sperm include the **flagellum** and the presence of enzymes. The adaptive features of the egg cells include the jelly coating, which changes after fertilisation, and the energy stores. Fig. 10.22 shows the main adaptive features of the human sperm cell and egg cell.


acrosome containing enzymes
nucleus
many mitochondria
flagellum
large amount of cytoplasm containing food (energy stores)
nucleus
jelly coat

Δ Fig. 10.22 Left: human sperm. Right: human egg. (Not to scale: the egg cell is around five times larger than the length of a sperm cell.)

Sperm are among the smallest cells in the human body, at about 45 micrometres long. Over 100 million sperm cells are produced each day. There are many mitochondria in the part of the sperm between the head and the flagellum (tail). The mitochondria provide energy from respiration that allows the flagellum to beat back and forth to move the sperm cell.

Most of the cell is formed by the flagellum, which propels the sperm through the female uterus to the egg for fertilisation. At the front tip of the sperm is a small sac of enzymes called the **acrosome**. When a sperm reaches an egg cell, the acrosome bursts open to release the enzymes. The enzymes digest through the jelly coat and cell membrane of the egg cell, allowing the male nucleus to enter the egg cell.

The egg cell is one of the largest human cells, at about 0.2 mm in diameter. It cannot move on its own, but is wafted along the oviduct by cilia on the inside of the tube. An ovary may contain thousands of egg cells, but only one is usually released from one ovary at **ovulation** each month. Within the egg cell is the nucleus and a large amount of cytoplasm. The cytoplasm provides nutrients for the dividing zygote after fertilisation. Surrounding the cell membrane is a jelly coat that protects the cell. Immediately after fertilisation by one sperm, the jelly coat changes to an impenetrable barrier. This prevents other sperm nuclei entering the egg cell.

END OF EXTENDED

QUESTIONS

1. a) Sketch a diagram of the human male reproductive system.
   b) Add labels to your sketch to name the main parts of the system.
   c) Describe the role of each of the main parts of the system in human reproduction.
2. a) Sketch a diagram of the human female reproductive system.
   b) Add labels to your sketch to name the main parts of the system.
   c) Describe the role of each of the main parts of the system in human reproduction.
3. EXTENDED Draw up a table to compare the size, numbers and mobility of human egg and sperm cells.

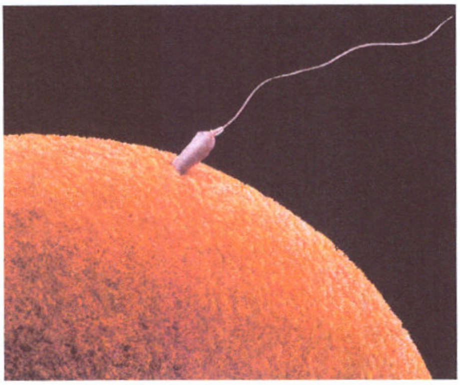
Fertilisation and development of the fetus

During sexual intercourse, sperm deposited near the cervix swim up into the uterus, and then along the oviduct to the egg. Many sperm fail to make the journey, but some will reach the oviducts at the top end of the uterus.

The egg will have been travelling along the oviduct while the sperm have been swimming up from the uterus. Fertilisation takes place in the oviduct. The nucleus of one sperm cell fuses with the nucleus of the egg cell, forming a fertilised egg, or zygote.

After fertilisation in the oviduct, the fertilised egg (zygote) travels on toward the uterus. The journey takes about 3 days, during which time the zygote will divide several times to form a ball of 64 cells, which is now called an **embryo**.

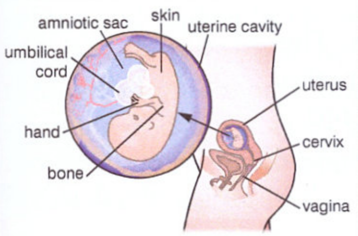
In the uterus, the embryo embeds in the thickened lining (**implantation**) and cell division and growth continue. For the first 3 months, the embryo gets nutrients from the mother by diffusion through the uterus lining.



Δ Fig. 10.23 The moment just before fertilisation: sperm approaching an egg.

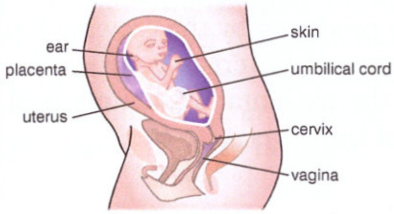
By the end of 3 months, the placenta has developed, and the embryo has become a **fetus** in which all the main organs of the body can be identified.

Over the next 28 weeks the fetus will increase its mass roughly 8 million times. At no other point in an individual's lifetime will growth occur at such a high rate. This period of development in the uterus is known as *gestation*, and it lasts about 40 weeks in humans, measured from the time of the woman's last period. The rapid growth during gestation depends on a good supply of food and oxygen, provided by the mother.


amniotic sac
skin
uterine cavity
umbilical cord
uterus
hand
cervix
bone
vagina

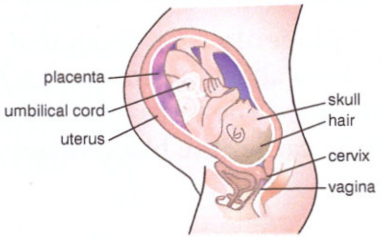
11 weeks:

- fetus about 4 cm long
- most of the main body structures have formed


ear
skin
placenta
umbilical cord
uterus
cervix
vagina

23 weeks:

- fetus about 29 cm long and weighs about 500 g
- fetus hears sound from outside, and moves


placenta
umbilical cord
uterus
skull
hair
cervix
vagina

40 weeks:

- fetus is about 51 cm long and weighs about 3.4 kg
- all organs fully developed ready for birth

Δ Fig. 10.24 The fetus in the uterus at three time points during gestation.

SCIENCE IN CONTEXT

ULTRASOUND SCANS

Ultrasound is very high frequency sound, far above the frequency that can be heard. It is used in medical imaging for showing soft tissues inside the body. It is particularly useful for looking at the developing fetus in the uterus, because it does not harm either the fetus or the mother.

An ultrasound scan is commonly done about halfway through gestation, to make sure that the fetus is developing normally. At about this stage, if the fetus is lying at the right angle, it may even be possible to tell if it is a male fetus because the testes can be distinguished at this age.

Ultrasound scans may be done at other times during gestation if there is any concern about the development of the fetus.

HOSPITAL
OBST
16:13

Δ Fig. 10.25 This ultrasound scan was taken in the 20th week of gestation and shows that the fetus is developing normally.

The fetus develops inside a bag of fluid called **amniotic fluid.** This fluid is produced from the amniotic membrane that forms the outer layer of the bag (**amniotic sac**). The fluid protects the fetus from mechanical damage, for example if the mother moves suddenly. It also reduces the effect of large temperature variations that would affect the rate of development of the fetus. One of the signs that birth will happen soon is when this bag bursts shortly before **labour**. Once the placenta has formed, until birth, it is the only way that the developing fetus exchanges materials with the outside world. Birth usually occurs when all the organs of the fetus are fully developed and ready to carry out the life processes on their own.

The **placenta** is an organ that is produced by the growing fetus. The placenta allows a constant exchange of materials between the mother and fetus. The fetus is joined to the placenta by the umbilical cord, which carries the blood vessels of the fetus.

EXTENDED

The placenta and the uterus wall have a large number of blood vessels that run very close to each other, but do not touch. So maternal and fetal blood do not mix. If they did, the higher blood pressure in the mother could damage the fetus. The structure of the placenta also helps to prevent many pathogens and some chemicals getting into the blood of the fetus. However, some pathogens (such as the rubella virus) and chemicals (such as nicotine from tobacco smoke) are small enough to cross through the placenta from the mother into the fetus and cause harm to the fetus.

Dissolved food molecules, oxygen and other nutrients that the fetus needs for growth diffuse from the mother's blood into the blood of the fetus. Waste products from metabolism, such as carbon dioxide and urea, in the fetus's blood diffuse across into the mother's blood.

END OF EXTENDED

QUESTIONS

1. Define the following terms in your own words: **a)** *zygote*, **b)** *embryo*, **c)** *fetus*.
2. Where in the human body does fertilisation of the egg cell occur?
3. Briefly describe how the fetus develops up to the point of birth.
4. **EXTENDED** Describe the role of the placenta during the development of a fetus.

SEXUALLY TRANSMITTED INFECTIONS (STIs)

Unfortunately, sexual intercourse is a method by which infection can spread, because of the exchange of body fluids, which may contain pathogens. There are many **sexually transmitted infections**, including **HIV**, which usually leads to acquired immunodeficiency disease (**AIDS**).

AIDS

AIDS is a disease of the immune system caused by a virus called HIV. The virus in an infected person is present in sexual fluids, such as semen and vaginal fluids, and so can be transmitted during sexual intercourse. It may also be passed to another person in blood, either through a scratch, or through the sharing of needles for intravenous injection of drugs such as **heroin**. Infection can also pass from a mother to her fetus through the placenta, or to her baby through breast-feeding after birth.

There is no cure for AIDS, so prevention of infection is essential. This is most easily done by abstinence from sex, or by limiting sexual partners to those who do not carry the virus. As a person may have no obvious symptoms early in infection, barrier methods such as the **condom** or **femidom** are most effective in reducing the risk of infection during intercourse.

MINISTRY OF PUBLIC HEALTH
CHAD-TAIWAN COOPERATION
NATIONAL PROGRAM OF FIGHT AGAINST AIDS
STI/HIV/AIDS PREVENTION PROJECT ON COMMUNICATION WAYS
BEWARE!
AIDS IS ON LOOK OUT FOR YOU AT EACH STOP
FIDELITY
MAY I GO WITH YOU?
NO! WITH OR WITHOUT CONDOM NO.
ABSTINENCE
Let us go to the hotel!
Ok! but with condom
CONDOM
100% PRUDENCE
AIDS
SPONSOR : TAIWAN
OWNERS : MSP/PNLS/IST
EXECUTION : CARE CHAD
PARTNERS : COMMUTERS' UNION FOSAP/PPLS/ONUSIDA
TCHAD MSP
PNLS FOSAP PPLS
ONUSIDA
care

Δ Fig. 10.26 Advertising: the use of condoms during sexual intercourse can help prevent the spread of the HIV virus.

QUESTIONS

1. Explain what we mean by a *sexually transmitted infection*.
2. Describe the methods of transmission of HIV.
3. Describe the effect of HIV on the body.
4. Describe two ways to prevent the transmission of HIV during sexual intercourse.

End of topic checklist

Key words

AIDS, amniotic fluid, cervix, embryo, fetus, HIV, labour, menstrual cycle, ovary, ovulation, placenta, sexually transmitted infection, sperm, testis, uterus, vagina

During your study of this topic you should have learned:

○ How to identify and name parts of the human male reproductive system, including the testes where sperm are made; the sperm ducts, which carry the sperm to the urethra; the prostate gland, which produces liquid in which the sperm swim; the penis, which when erect delivers sperm into the vagina of the woman; and the urethra, which carries the sperm from the sperm ducts to the outside of the body.

○ How to identify and name parts of the human female reproductive system, including the ovaries, where the egg cells are made; the oviducts, which carry the eggs to the uterus and where fertilisation takes place with sperm cells; the uterus, where the embryo embeds and develops into a fetus; the cervix, where sperm are deposited at the base of the uterus; and the vagina, where the penis is inserted during sexual intercourse.

○ About the menstrual cycle during which an egg is released from the ovary, and the uterus lining thickens. If fertilisation does not take place, the uterus lining and egg are shed at the start of the next cycle.

○ **EXTENDED** Once the embryo has embedded in the uterus wall, the placenta develops. This is where nutrients and waste materials are exchanged between the blood of the mother and of the fetus.

○ During development, the embryo (and later the fetus) is protected from mechanical damage and temperature fluctuations by amniotic fluid that surrounds it in the amniotic sac.

○ **EXTENDED** That some toxins can pass across the placenta and affect the fetus.

○ AIDS is a disease caused by a virus that may be transmitted during sexual intercourse, or in blood, through the placenta or in breast milk.

○ HIV causes AIDS by damaging the immune system, so the person may be infected by other pathogens.

End of topic questions

1. **a)** Where are sperm cells made in the human body? **(1 mark)**

   b) Where are egg cells made in the human body? **(1 mark)**

   c) Where is an egg cell fertilised by a sperm cell? **(1 mark)**

   d) Starting from the point of their formation, explain how a sperm cell reaches the egg cell at fertilisation. **(4 marks)**

2. Draw the menstrual cycle as a circle of 28 days. On your diagram label:

   a) ovulation **(1 mark)**

   b) menstruation **(1 mark)**

3. **a)** EXTENDED What is the *placenta*? **(1 mark)**

   b) EXTENDED What role does the placenta play in supporting the fetus? **(1 mark)**

   c) EXTENDED How are substances exchanged across the placenta? **(2 marks)**

   d) EXTENDED What is the advantage of keeping the mother's blood separated from the blood of the fetus? **(1 mark)**

4. **a)** Explain why HIV is classified as a sexually transmitted infection. **(1 mark)**

   b) Describe two ways in which HIV can be transmitted from a mother to her baby. **(2 marks)**

   c) Explain why someone with HIV is unlikely to die from that virus, but may die from other infections. **(2 marks)**

In the 1990s an international group of scientists embarked on the Human Genome Project, an ambitious research effort to read the whole sequence of human DNA and identify all the genes that it contains. Completed in 2003, the project surprisingly found that the 3 billion or so base pairs of DNA that make up the human genome equate to only about 20 000 genes, far fewer than was originally thought.

CONTENTS

a) Chromosomes and genes
- b) Genetic inheritance

c) Cell division
- d) Mitosis
- e) Meiosis

f) Monohybrid inheritance
- g) Single gene characteristics
- h) Monohybrid crosses

i) Variation and selection
- j) Variation
- k) Selection

11
Inheritance

Δ Just before nuclear division, each chromosome is copied exactly. The two copies then separate as new cells are made.

Δ Fig. 11.1 This baby will have inherited some characteristics from her mother and some from her father.

Chromosomes and genes

INTRODUCTION

Unless a zygote (fertilised egg) divides completely into two separate cells on its first division, and develops as two identical twins, the baby that develops from that zygote is genetically unique. Each cell in a zygote contains genetic information, half of which came from the father and half from the mother. And during gamete formation, some changes will have occurred in some of that genetic information. So the baby will have about 100 variations in its genes that neither of its parents has. Interestingly, although the baby is genetically unique, virtually all of the cells in its body are genetically identical.

KNOWLEDGE CHECK

- ✓ Organisms show variation in their features.
- ✓ Genes are small parts of the genetic information (DNA) found in the nucleus of a cell.

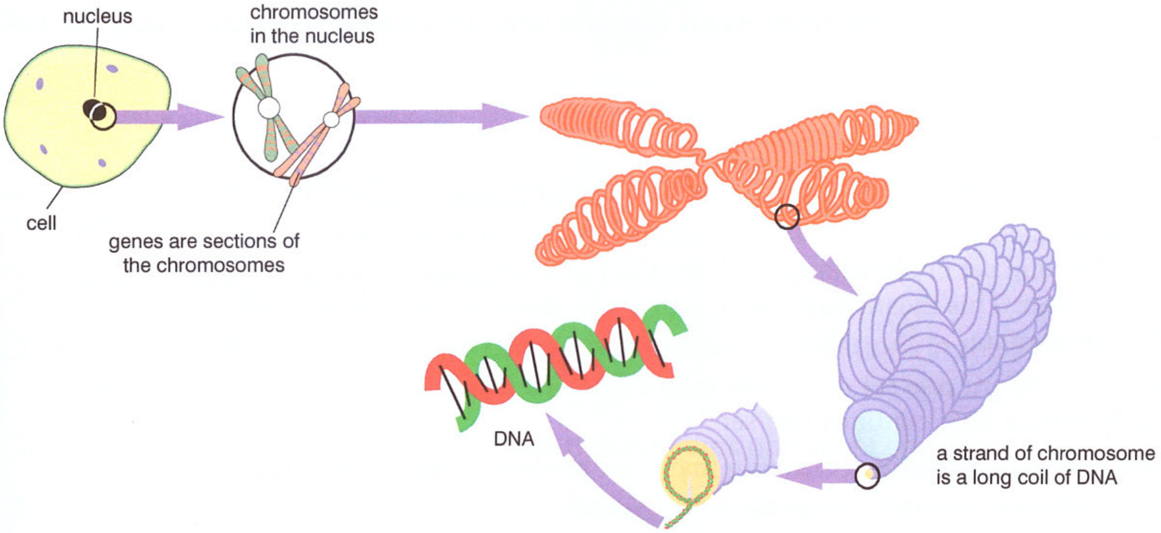
LEARNING OBJECTIVES

- ✓ Define *inheritance* as the transmission of genetic material from one generation to the next.
- ✓ Define a *chromosome* as a thread-like structure of DNA, carrying genetic information in the form of genes.
- ✓ Define a *gene* as a length of DNA that codes for a protein.
- ✓ Define an *allele* as a version of a gene.
- ✓ Describe the inheritance of sex in humans with reference to XX and XY chromosomes.
- ✓ **EXTENDED** Define *haploid nucleus* and *diploid nucleus* in terms of how many chromosomes each contains.
- ✓ **EXTENDED** State that, in a diploid cell, chromosomes are arranged in pairs and in a human diploid cell there are 23 pairs.

GENETIC INHERITANCE

Inheritance is the passing on (transmission) of characteristics from one generation to the next, from parents to offspring. As characteristics are coded for by genetic information in the cell nucleus, inheritance is also the transmission of genes from the parents' gametes to the offspring.

Inside virtually every cell in the body is a nucleus, which contains long threads called **chromosomes**. These threads are usually stretched out and fill the nucleus but, when the chromosomes condense (gather into bundles) just before cell division, they can be seen through a microscope. The chromosomes are made of a chemical called deoxyribonucleic acid **(DNA)**.


nucleus
chromosomes in the nucleus
cell
genes are sections of the chromosomes
DNA
a strand of chromosome is a long coil of DNA

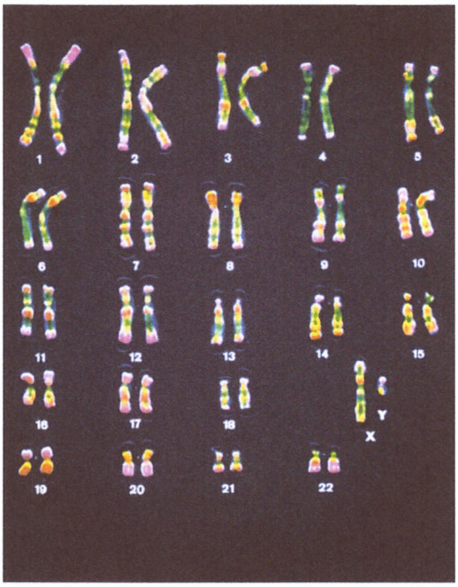
Δ Fig. 11.2 The relationship between cell, nucleus, chromosome and DNA.

Genes and alleles

Small sections of the DNA code for different proteins. These small sections are called **genes**. During cell division the string of genes on each chromosome is copied and passed on to the new cells.

Genes code for particular characteristics, such as eye colour. However, variations in a characteristic are caused by different forms of a gene, called **alleles**. For example, some people have alleles that code for brown eye colour; others have alleles that code for hazel eyes, or blue eyes or grey eyes.

In the identical pairs of chromosomes, both chromosomes have the same genes in the same order, but the genes on each chromosome may be in the form of the same allele or different alleles. This causes differences in inheritance (as you will see below).


1
2
3
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18
19
20
21
22
X
Y

Δ Fig. 11.3 The chromosomes from a man's body cell arranged in their pairs. The chromosomes in each pair look very similar except in the **sex chromosome** pair (marked X and Y).

QUESTIONS

1. Put the following in order of size, starting with the smallest: cell, chromosome, gene, nucleus.
2. Using an example, explain the difference between *gene* and *allele*.
3. Define the term *inheritance* as fully as you can.

EXTENDED

Chromosome sets

Most of the cells in the body contain two sets of chromosomes. This is because each individual that is produced by sexual reproduction receives one set of chromosomes from their mother and one set from their father. This means you will inherit some characteristics from each of your parents.

You only inherit one set of chromosomes from each parent, because each gamete only contains one set.

Body cells are **diploid** – meaning that their nucleus contains two sets of chromosomes. Each chromosome is paired.

The gametes, however, are **haploid** – the nucleus of these cells (sperm, egg cell, male gamete in pollen grain) contains only one set of chromosomes. This is the result of the way that they are produced during meiosis.

In humans, the nucleus of diploid cells contains 46 chromosomes, and the nucleus of haploid gamete cells contains 23 chromosomes.

END OF EXTENDED

End of topic checklist

Key words

allele, chromosome, diploid, DNA, haploid, inheritance

During your study of this topic you should have learned:

○ Inheritance is the transmission of genetic information from generation to generation.

○ A chromosome is a long thread of DNA, carrying genetic information in the form of genes.

○ A gene codes for a specific protein.

○ Genes have alternative forms called alleles that produce variations in the protein or characteristic.

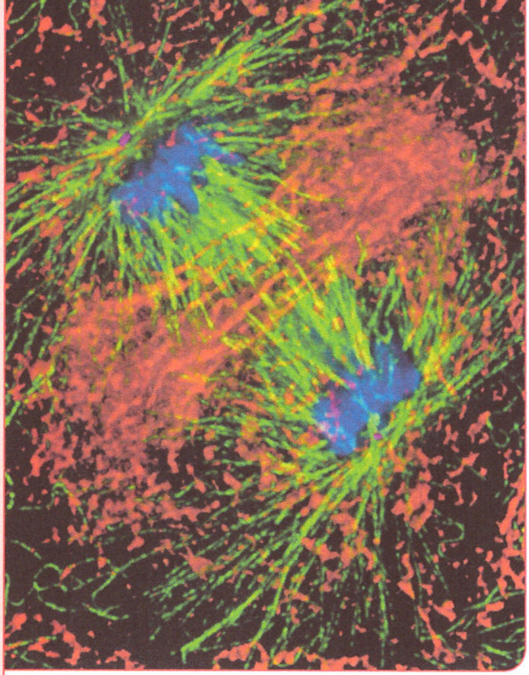
○ **EXTENDED** A haploid cell has a nucleus that contains one set of chromosomes.

○ **EXTENDED** A diploid cell has a nucleus that contains two sets of chromosomes, and human diploid cells have 23 pairs of chromosomes.

End of topic questions

Note: The marks given for these questions indicate the level of detail required in the answers. In the examination, the number of marks given to questions like these may be different.

1. Write two sentences that correctly link all the following words to explain how they are related: *characteristic, chromosome, DNA, gene, nucleus, protein.* **(2 marks)**
2. Explain why there are two sexes in humans, using the inheritance of sex to support your answer. **(4 marks)**



Δ Fig. 11.4 An electron micrograph of a cell undergoing mitosis.

Cell division

INTRODUCTION

Mitosis is a type of nuclear division used to make identical cells for growth, repair and asexual reproduction.

Meiosis is a different type of cell division that makes gametes to be used in sexual reproduction.

KNOWLEDGE CHECK

✓ Cell division is needed for growth, repair and reproduction.
✓ Mitosis is the process for forming new identical body cells.
✓ Meiosis is the process for making egg and sperm cells.

LEARNING OBJECTIVES

✓ **EXTENDED** Define *mitosis* as nuclear division giving rise to genetically identical cells.
✓ **EXTENDED** State that the exact duplication of chromosomes occurs before mitosis.
✓ **EXTENDED** State the role of mitosis in growth, repair of damaged tissues, replacement of cells and asexual reproduction.
✓ **EXTENDED** Define *meiosis* as reduction division in which the chromosome number is halved from diploid to haploid, resulting in genetically different cells.
✓ **EXTENDED** State that meiosis is involved in the production of gametes.

EXTENDED

MITOSIS

Organisms grow by the division of cells, whereby the body cells split in two. Before a cell can split, its nucleus must first divide in two. This kind of division is used to produce new body cells in growth, the repair of damaged tissues and replacement of cells in the body. It is also the way that single-celled organisms reproduce and is the only type of cell division involved during asexual reproduction (reproduction that does not involve sex cells), as you saw in Topic 10. This type of cell division, in which the new cells are genetically identical to the original cell, is known as **mitosis**.

Before a cell divides in mitosis, its chromosomes are duplicated (copied). During mitosis, the copies of the chromosomes separate, so that one copy of each chromosome ends up in each of the new (daughter) cells. This is why the **daughter cells** are genetically identical to the original cell.

MEIOSIS

During sexual reproduction, a male gamete fuses with a female gamete. If each gamete had the same number of chromosomes as a normal body cell, the zygote would end up with twice as many chromosomes as normal. Instead, gametes are produced by a different form of cell division called **meiosis**. This is a **reduction division** because the cells produced by meiosis have a reduced number of chromosomes, just one chromosome of each pair – half the normal number of chromosomes. These cells are called haploid cells. When the gametes fuse during fertilisation, they restore the normal number of chromosomes, creating a diploid cell with pairs of chromosomes again.

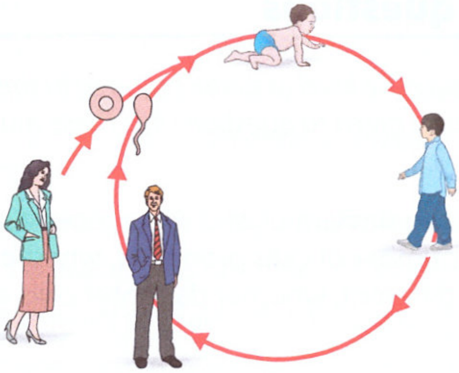
Cells produced by meiosis are not identical. This means that, during fertilisation where there is a random chance that any one male gamete will fuse with the female gamete, the offspring produced will be different from each other. We say they show variation.

QUESTIONS

1. a) Which form of cell division produces new body cells?

b) Explain why this is important to the organism.

2. The diagram shows the life cycle of a human.



Copy the diagram and annotate it to show:

- when meiosis and mitosis occur
- which cells are diploid and which are haploid.

3. EXTENDED Name the form of cell division that is found in organisms that reproduce by: (a) sexual reproduction, (b) asexual reproduction.

4. EXTENDED Explain the importance of meiosis in producing variation in offspring.

END OF EXTENDED

End of topic checklist

Key words

diploid, haploid, meiosis, mitosis

During your study of this topic you should have learned:

- ○ **EXTENDED** Mitosis is the division of the nucleus of a body cell to produce two genetically identical cells. Mitosis produces new cells during growth and repair of body cells and in asexual reproduction.
- ○ **EXTENDED** Before mitosis, the chromosomes are duplicated.
- ○ **EXTENDED** During mitosis, one copy of each chromosome moves into each daughter cell, which results in two diploid cells that are genetically identical to each other.
- ○ **EXTENDED** Meiosis is a nuclear division result in genetically different cells such as in the production of gametes.
- ○ **EXTENDED** Meiosis is a reduction division producing haploid cells from a diploid cell, and produces variation by forming new combinations of maternal and paternal chromosomes.

End of topic questions

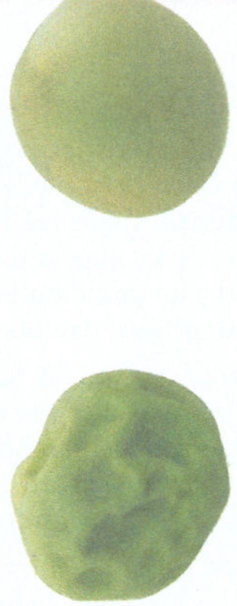
Note: The marks given for these questions indicate the level of detail required in the answers. In the examination, the number of marks given to questions like these may be different.

1. **EXTENDED** Draw up a table to summarise the similarities and differences between mitosis and meiosis in terms of: number of cells produced, whether daughter cells are genetically identical or different, whether daughter cells are haploid or diploid, and what its purpose is. **(8 marks)**
2. **EXTENDED** Explain why a life cycle needs a stage in which meiosis occurs before fertilisation. **(2 marks)**

Monohybrid inheritance

INTRODUCTION

Some characteristics are controlled by a single gene, and we can track the patterns of inheritance from generation to generation. By looking at the patterns, we can make conclusions about how the alleles of that gene work and find out whether they are dominant or recessive.



Δ Fig. 11.5 These peas show a monohybrid characteristic; smooth is a dominant characteristic and wrinkled is a recessive characteristic.

KNOWLEDGE CHECK

✓ Characteristics are inherited through genes.
✓ Children get half of their genes from their mothers and half of their genes from their fathers.

LEARNING OBJECTIVES

✓ Define *genotype* as the genetic make-up of an organism in terms of the alleles present.
✓ Define *phenotype* as the observable features of an organism.
✓ Define *homozygous* as having two identical alleles of a particular gene.
✓ State that two identical homozygous individuals that breed together will be pure-breeding.
✓ Define *heterozygous* as having two different alleles of a particular gene.
✓ State that heterozygous individuals will not be pure-breeding.
✓ Define *dominant* as an allele that is expressed if it is present.
✓ Define *recessive* as an allele that is only expressed when there is no dominant allele of the gene present.
✓ Use genetic diagrams to predict the results of monohybrid crosses and calculate phenotypic ratios.
✓ Use Punnett squares in crosses which result in more than one genotype to work out and show the possible different genotypes.
✓ **EXTENDED** Interpret pedigree diagrams for the inheritance of a given characteristic.

SINGLE GENE CHARACTERISTICS

Some characteristics, such as the colour of your eyes, are passed down (inherited) from your parents, but other characteristics may not be passed down. Sometimes characteristics appear to miss a generation: for instance, you and your grandmother might both have dry earwax but both of your parents may have wet earwax.

Leopards occasionally have a cub that has completely black fur instead of the usual spotted pattern. It is known as a black panther, but is still the same species as the ordinary leopard. Just as in humans, leopard chromosomes occur in pairs. One pair carries a gene for fur colour.

There are two copies of the gene in a normal body cell (one on each chromosome). The version of the gene (allele) may be identical but sometimes they are different, one being for a spotted coat and the other for a black coat.

Leopard cubs receive half their genes from each parent. Eggs and sperm cells contain only half the number of chromosomes of normal body cells. This means that egg and sperm cells contain only one of each pair of alleles. When an egg and sperm join together at fertilisation, forming a zygote that will develop into the new individual, it now has two alleles of each gene.

Different combinations of alleles will produce different fur colour:

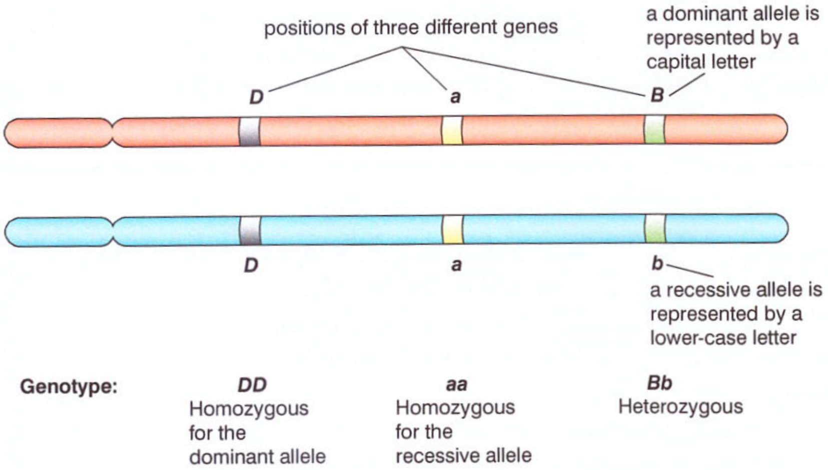
Δ Fig. 11.6 Two spotted leopard parents may produce offspring with a spotted coat or a black coat.

spotted coat allele + spotted coat allele = spotted coat
spotted coat allele + black coat allele = spotted coat
black coat allele + black coat allele = black coat

The black coat only appears when *both* of the alleles for the black coat are present. As long as there is at least one allele for a spotted coat, the coat will be spotted because the allele for a spotted coat overrides the allele for a black coat. It is the **dominant** allele. A dominant allele is the allele that is expressed in the phenotype. Alleles like the one for the black coat are described as **recessive**. The recessive allele is the allele that is not expressed in the phenotype unless there are two copies present.

An individual with two identical alleles for a gene is said to be **homozygous** (*homo* means 'the same') for that gene.

An individual with two different alleles for a gene is said to be **heterozygous** for that gene (*hetero* means 'different').


positions of three different genes
a dominant allele is represented by a capital letter
D
a
B
D
a
b
a recessive allele is represented by a lower-case letter
Genotype:
DD
Homozygous for the dominant allele
aa
Homozygous for the recessive allele
Bb
Heterozygous

Δ Fig. 11.7 Definitions in genetics.

Identical homozygous individuals that breed together will be pure-breeding; heterozygous individuals that breed together will not be pure-breeding. A leopard with a spotted coat may be homozygous for the spotted allele, or heterozygous. A leopard with a black coat can only be homozygous for the black allele.

QUESTIONS

1. Define the following terms in your own words:

a) *dominant* **b)** *recessive* **c)** *homozygous* **d)** *heterozygous*.

2. How many alleles for a particular gene would be found in:

a) a body cell **b)** a gamete **c)** a zygote?

3. EXTENDED A sperm cell of a leopard contains 19 chromosomes. How many chromosomes are there in the nucleus of a leopard's body cell? Explain your answer.

MONOHYBRID CROSSES

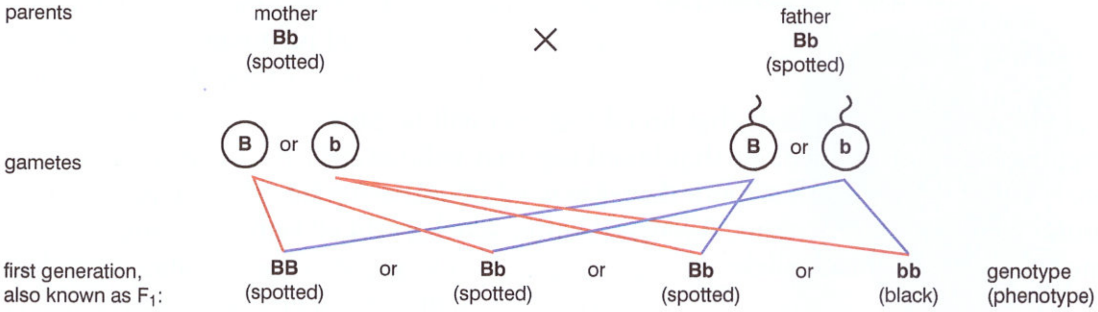
An individual's combination of genes is his or her **genotype**. An individual's combination of physical features is his or her **phenotype**. Your genotype influences your phenotype.

We can show the influence of the genotype in a **genetic diagram**. This uses a capital letter for the dominant allele and a lower-case letter for the recessive allele.

REMEMBER

To avoid the risk of confusion when drawing genetic diagrams, we choose a letter that is easily distinguished in capital and lower case. For example, S or C for the coat gene might seem reasonable to use for the leopard example, but this gives alleles S/s or C/c, which may be confusing.

Using the example of the leopards, **B** stands for the dominant allele for a spotted coat and letter **b** stands for the recessive allele for the black coat. Two spotted parents who have a black cub must each be carrying a **B** and a **b**. The genetic diagram below shows the possible genotypes and phenotypes of the offspring.


parents
mother
Bb
(spotted)
×
father
Bb
(spotted)
gametes
B
or
b
B
or
b
first generation, also known as F_1:
BB
(spotted)
or
Bb
(spotted)
or
Bb
(spotted)
or
bb
(black)
genotype
(phenotype)

Δ Fig. 11.8 Three different genotypes are possible from the cross in this diagram. The probability of each genotype is 1BB : 2Bb : 1bb.

Because we are looking at a characteristic (fur colour) controlled by one gene, this is an example of a **monohybrid cross**. *Mono* means 'one', and a *hybrid* is produced when two different types breed or cross.

Another type of genetic diagram is known as a *Punnett square*. The example above can be shown in a Punnett square. The four boxes at the bottom right show the possible combinations in the offspring.

			male Bb spotted	
			gametes	
			B	b
female Bb spotted	gametes	B	BB spotted	Bb Spotted
		b	Bb spotted	bb black

Probabilities and predictions

If you cross two individuals that are homozygous for the same alleles, then you will always get offspring that are homozygous for those alleles. We say that these individuals are pure-breeding. If you cross heterozygous individuals, you will get variety in the offspring. So heterozygous individuals are not pure-breeding.

When two heterozygous parents are crossed, the phenotype of the offspring with the dominant allele and the offspring with the recessive allele appears in the ratio of 3 : 1. The 3 : 1 ratio refers to the probabilities of particular combinations of alleles, so the chance of having an offspring with the phenotype of the dominant allele is three times the chance of having an offspring with the phenotype of the recessive allele.

In the example of the leopards, there is a 1 in 4, or 25% chance of a leopard cub being black. This is because the offspring must inherit two recessive alleles (one from each parent) in order for the offspring to be homozygous and for the phenotype to be expressed (visible).

With a large number of offspring in an *actual* cross of two heterozygous leopard parents, you would expect something near the 3 : 1 ratio of spotted to black cubs. However, because it is a matter of chance which sperm cell fertilises which egg cell, you should not be too surprised if a small litter – for example, of four cubs – contained two black cubs, or none.

Using the example of leopard coat colour and a Punnett square, we can also look at what happens if we cross homozygous recessive and heterozygous individuals:

			male Bb spotted	
			gametes	
			B	b
female bb black	gametes	b	Bb spotted	bb black
		b	Bb spotted	bb black

The predicted outcome from this cross is a 1 : 1 ratio of spotted to black colouring. This gives a 1 in 2, or 50% chance of a cub from these parents being spotted or being black.

REMEMBER

You need to be able to predict probabilities of outcomes from any monohybrid cross. Practice drawing genetic diagrams to make sure you are confident with them.

Can you predict what will happen if a homozygous spotted coat leopard is crossed with a heterozygous spotted coat leopard?

			male Bb spotted	
			gametes	
			B	b
female BB spotted	gametes	B	BB spotted	Bb spotted
		B	BB spotted	Bb spotted

In this case, although some of the cubs are likely to be homozygous and some heterozygous, they will all have spotted coats. They will have the same phenotype, but not the same genotype.

QUESTIONS

1. Define *monohybrid inheritance* in your own words.

2. Rabbits have a gene for coat colour – the allele for brown coat is dominant over the allele for black coat colour. Using the letter B for the dominant allele, and b for the recessive allele, write down all the possible genotypes and phenotypes for this gene. Explain your answers.

3. Using your answers from Question 2:

a) Construct a genetic diagram to show the possible offspring from a cross between a male rabbit that is homozygous for the dominant allele and a female rabbit that is homozygous for the recessive allele.

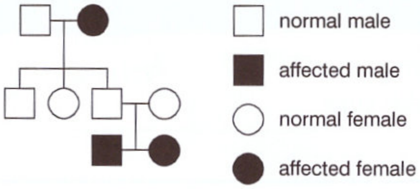
b) What is the probability of producing a black baby rabbit from this cross?

EXTENDED

Pedigree diagrams

Scientists use pedigree diagrams to track a characteristic across generations and to interpret what whether it is dominant or recessive.

Recessive characteristics can be identified because they can sometimes skip a generation, whereas dominant characteristics are present in every generation.



Δ Fig. 11.9 Pedigree chart showing the inheritance of a recessive characteristic.

Developing investigative skills

In an investigation into the inheritance of a characteristic, students used red beads to represent dominant alleles and blue beads to represent recessive alleles.

As a homozygous dominant individual produces gametes that only contain the dominant allele, all the red beads were placed into a beaker to represent the gametes for this individual. As a homozygous recessive individual produces gametes that only contain the recessive allele, all the blue beads were placed into another beaker to represent the gametes for this individual.

To model what would happen in a cross between these two individuals, they took one gamete (bead) from one pot and paired it with one gamete (bead) from the other pot and wrote down the genotype and phenotype for that 'offspring'. This showed that all the offspring from these parents would be heterozygous (one red, one blue bead).

Devise and plan investigations

❶ Describe and explain how you would adapt this method to represent a cross between two heterozygotes. (Hint: Make sure you use enough beads to get a reasonable approximation of the actual result to the expected result.)

Analyse and interpret data

Some students carried out an investigation like this that started with two 'parents' which were heterozygous for a characteristic.

❷ Each pot started with 40 beads. How many red beads and how many blue beads were in each of the two pots? Explain your answer.

Only 20 selections were made from the two beakers, to produce the 'offspring'. The results are shown in this table.

Number of red/red pairs in 'offspring'	5
Number of red/blue pairs in 'offspring'	12
Number of blue/blue pairs in 'offspring'	3

❸ Draw a genetic diagram for this cross, to show the predicted probabilities of genotypes and phenotypes. (Hint: remember to choose letters for the alleles and explain which allele is modelled by the red beads and which by the blue beads.)

❹ Describe how the actual results differ from the expected results.

Evaluate data and methods

❺ Comment on the difference between the expected and actual results.

❻ Explain how you would adjust the method to help improve the results.

SCIENCE IN CONTEXT

MENDEL'S PEAS

Gregor Mendel (1822–1884) was the first person to study genetic inheritance in a thorough and scientific manner. He chose characteristics in peas to study because he could see clear differences in characteristics and patterns in their inheritance. He started by crossing plants with the same characteristics many times, until he was certain that they were pure-breeding.

He then made hundreds of crosses of the same kind. He started by removing the anthers of each flower. Then he brushed pollen from a plant he had chosen for one parent on to the stigma of the other 'parent' and covered the flower to prevent other pollen getting in.

From his results, Mendel was able to show that alleles generally do not mix effects in the phenotype, but that a dominant allele in a heterozygote prevents the recessive allele being expressed.

Δ Fig. 11.10 The results of one of Mendel's crosses for pea form and colour. (Note that each pea is the result of a separate cross between a pollen grain and an egg cell.)

1. Why was it important that the parent plants were pure-breeding?
2. Why did Mendel need to carry out hundreds of crosses before drawing a conclusion?
3. Pea flowers are pollinated by insects. How could Mendel be certain that no chance fertilisations took place?
4. At the time Mendel carried out his work, people couldn't understand how a characteristic could be present in one generation, 'disappear' in the next generation and then reappear in the next. Using genetic diagrams, and a characteristic of your choice, show how this happens when starting with pure-breeding parents for the dominant and recessive characteristics.
5. Explain the importance of a thorough and scientific method for drawing reliable conclusions.

End of topic checklist

Key words

dominant, genetic diagram, genotype, heterozygous, homozygous, monohybrid cross, phenotype, recessive

During your study of this topic you should have learned:

- ○ Dominant alleles in the genotype are always expressed in the phenotype, but recessive alleles are only seen in the phenotype when there is no dominant allele (there are two copies of the recessive allele).
- ○ A homozygous individual has two copies of the same allele; a heterozygous individual has different alleles for the gene.
- ○ Two identical homozygous individuals that breed together will be pure-breeding, but heterozygous individuals are not pure-breeding.
- ○ Monohybrid inheritance is the inheritance of a characteristic that is controlled by one gene. The predicted outcome of any cross can be shown in a genetic diagram, including a Punnett square.

End of topic questions

Note: The marks given for these questions indicate the level of detail required in the answers. In the examination, the number of marks given to questions like these may be different.

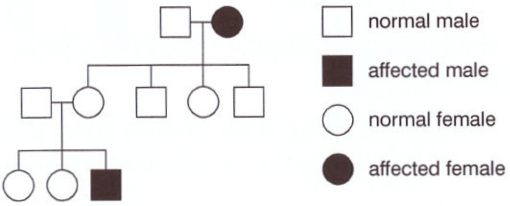
1. The form of earwax in humans is controlled by one gene. The dominant allele produces wet-type earwax, and the recessive allele produces dry earwax.

a) Using appropriate symbols, draw a genetic diagram to show the inheritance of earwax between a man with dry earwax and woman who is heterozygous for the characteristic. **(3 marks)**

b) Describe the predicted probability of genotypes and phenotypes in their children. **(2 marks)**

c) Explain why it is possible that their three children all have dry earwax. **(2 marks)**

2. EXTENDED Explain, with reasons, what kind of inheritance is shown in the pedigree diagram below. **(3 marks)**



Δ Fig. 11.11 How many variations can you spot between these individuals of the human species?

Variation and selection

INTRODUCTION

There is a huge range in variation between all the people on Earth today. We differ in many characteristics, such as size, skin colour, strength and hair type. Some of these characteristics are caused by genes and may stay the same throughout life. Some are also affected by the environment and so may change as we grow. Even though there is so much variation between people, we all belong to one species, *Homo sapiens*.

KNOWLEDGE CHECK

✓ Variation can be inherited or caused by the environment.
✓ Genes are small parts of the genetic information (DNA) found in the nucleus of a cell.

LEARNING OBJECTIVES

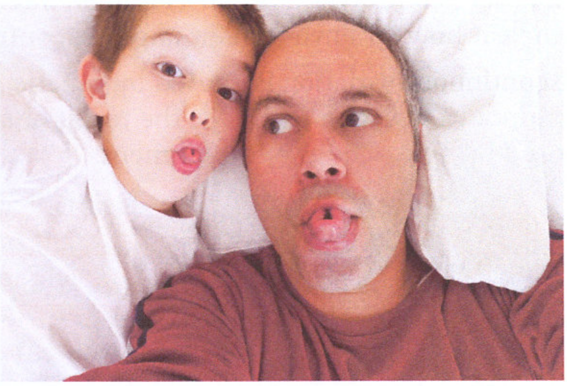
✓ Define *variation* as the differences between individuals of the same species.
✓ Distinguish between phenotypic and genetic variation.
✓ **EXTENDED** State that phenotypic variation is caused by both genes and the environment.
✓ State that continuous variation results in a range of phenotypes between two extremes, e.g. height in humans.
✓ **EXTENDED** Describe how discontinuous variation is mostly caused only by genes.
✓ Investigate continuous and discontinuous variation.
✓ State that discontinuous variation results in a limited number of phenotypes with no intermediates, e.g. tongue rolling.
✓ Describe how the rate of mutation can be increased by ionising radiation and by some chemical mutagens.
✓ **EXTENDED** Define *gene mutation* as a change in a gene or chromosome.
✓ **EXTENDED** State that ionising radiation and some chemicals increase the rate of mutation.
✓ Describe natural selection in terms of the best-adapted organisms having a better chance of passing on their genes to the next generation.
✓ **EXTENDED** Describe evolution as the change in adaptive features of a population over time as the result of natural selection.
✓ **EXTENDED** Define the process of *adaptation* as the process resulting from natural selection by which populations become more suited to their environment over many generations.

- ✓ **EXTENDED** Describe the development of strains of antibiotic-resistant bacteria as an example of evolution by natural selection.
- ✓ Describe selective breeding.
- ✓ **EXTENDED** State the differences between natural and artificial selection.
- ✓ **EXTENDED** Describe how selective breeding can be used to improve domesticated animals and crop plants.

VARIATION

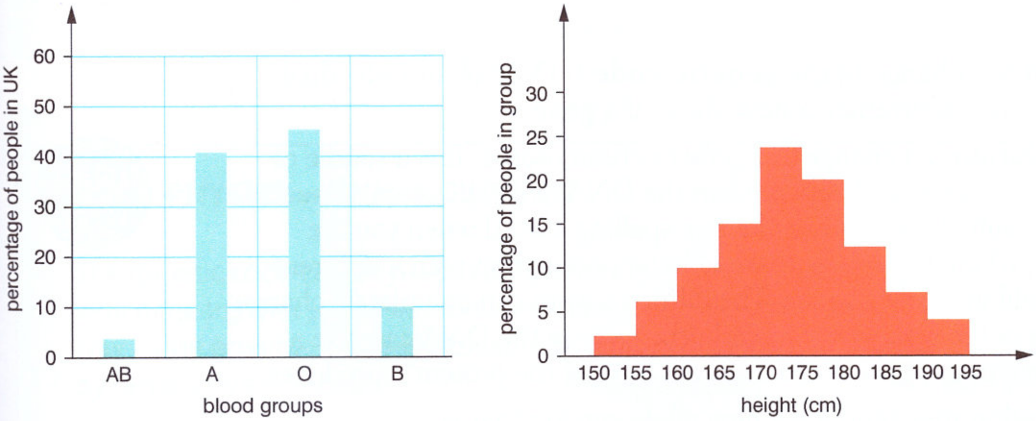
No two people are the same. Similarly, no two trees (of the same species) are exactly the same in every way. For example, they have different heights, different trunk widths and different numbers of leaves. Variation exists between members of the same species. We say that they show **phenotypic variation** because their features look different. Some of these differences are caused by differences in genes, which is **genetic variation**.

Phenotypic variation can be divided into two different types depending on how you are able to group the measurements.



Δ Fig. 11.12 Tongue-rolling: some people can roll the edges of their tongues inwards, whereas others cannot.

- **Discontinuous variation** (sometimes called discrete variation) is where a characteristic can have one of a limited number of specific phenotypes with no intermediates. For example, gender (you are either male or female), blood group (you are group A, B, AB or O), or tongue-rolling (you can either roll your tongue or not).
- **Continuous variation** is where a characteristic can have any value in a range: for example, body weight and length of hair. It results in a range of phenotypes between two extremes.



Δ Fig. 11.13 Charts showing discontinuous variation in human blood groups (left) and continuous variation in human height (right).

EXTENDED

The variation in appearance of characteristics in an individual may have various causes:

- **environmental causes**, such as your diet, the climate you live in, accidents, your surroundings, the way you have been brought up and your lifestyle
- **genetic causes** in characteristics that are controlled by your genes, such as eye colour and gender.
- Many characteristics are influenced by both *environment* and *genes*. For example, people in your family might tend to be tall, but unless you are healthy when you are growing you will not become tall, even though genetically you have the tendency to be tall. Other examples are more controversial, such as human intelligence, where it is unclear how far environment or genes contribute to variation.

Discontinuous variation is caused by genetic variation alone. Continuous variation is usually the result of a combination of variation caused by genes and the environment.

END OF EXTENDED

QUESTIONS

1. Explain what is meant by *variation*.
2. Name two types of variation of characteristics in a species, and give an example of each.
3. EXTENDED Describ e the source of the variation in each of these types of variation and explain your answer.

EXTENDED

Mutation

A **mutation** is a change in the **genetic code** (DNA) of an individual. For example, it can produce a new allele of a gene.

A **gene mutation** is a change in a gene or chromosome. It is a source of genetic variation and can happen when the DNA of a cell is copied, such as in cell division. This is rather like mis-spelling a word when you are copying text, where you use one wrong letter and end up with a different word (e.g. bold instead of bond). The different word can completely change the meaning of the sentence. Similarly, the error in the DNA can give a different allele of the gene and a different form of the protein it produces.

A gene mutation may produce a new allele version that is:

- beneficial for the organism, giving it an advantage over other individuals of the species; for example, fair skin is a mutation that has happened in human populations several times as they moved into areas of northern Europe and Asia, because it allows the individual to make more vitamin D from sunlight than those with darker skin

- neutral, which means it has no obvious effect; many mutations fall into this category and can only be identified by looking in detail at the genetic code
- harmful to the organism, either causing the early death of the embryo, or making the individual less able to survive than other individuals; many inherited diseases are caused by mutations of genes that produce proteins which are important in key processes.

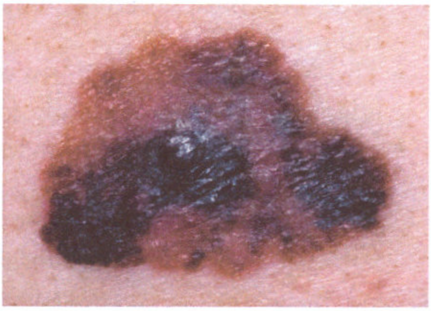
Causes of mutation

The incidence of mutation can be increased beyond the natural rate as the result of:

- exposure to **ionising radiation**, such as gamma rays, X rays and ultraviolet radiation
- chemical **mutagens**, such as some of the chemicals in tobacco.

These factors may change the genetic code directly or cause it to be miscopied more frequently during cell division.

One of the most obvious effects of radiation or chemical mutagens is to damage the control mechanisms that instruct a cell to stop dividing at the right time. The continuing division of cells produces a lump of unspecialised tissue called a **cancer**. Cancers that take over the space of other tissues can eventually cause death. In Europe and North America, the different forms of cancer are the greatest cause of death from disease.



Δ Fig. 11.14 This skin cancer was caused by too much ultraviolet radiation from sunlight.

QUESTIONS

1. **EXTENDED** Define the term *mutation* in your own words.
2. **EXTENDED** Name two different causes of gene mutation and give an example of each.

END OF EXTENDED

SCIENCE LINK

PHYSICS – ATOMIC PHYSICS

- The genetic code can be mutated from one generation to the next, which means that the DNA molecules have been altered in some way – one possible cause is exposure to ionising radiation emitted by radioactive sources.
- The different radioactive emissions can have different effects, depending on the type of radiation (alpha, beta and gamma radiations have different ionising abilities) and whether the exposure is from outside or inside the body (because of the different penetrating powers of the radiations).

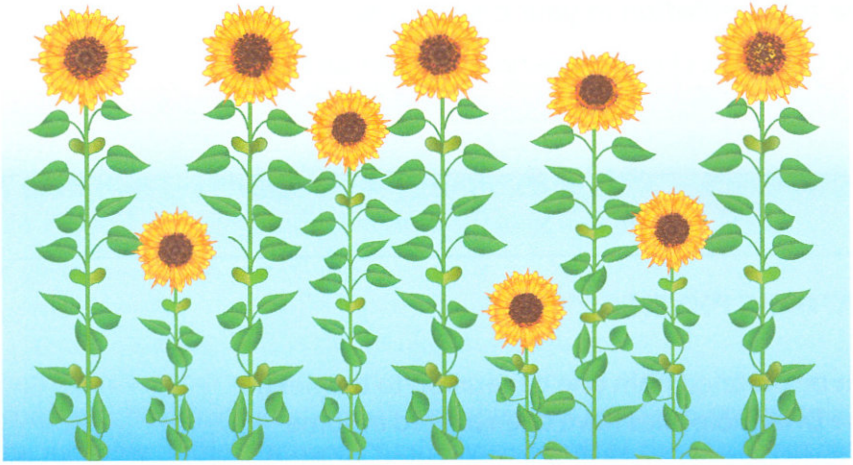
SELECTION

In any environment, the individuals that have the best **adaptive features** are most likely to survive and reproduce. This results in **natural selection** as follows:

- In any **population** of organisms there is variation between the individuals.
- When organisms reproduce, they produce more offspring than the environment is able to support. This means that there is competition between the offspring for food, or for mates or other resources that are limited. This competition results in a 'struggle for survival'.
- The offspring will have inherited their characteristics from their parents. However, they will have slightly different combinations of variations in characteristics than their parents as the result of sexual reproduction. Offspring with variations in adaptive features that help them compete better for resources, and get more of what they need, will have a better chance of surviving to adulthood and reproducing.
- Those individuals that have variations in features that are not as well adapted will be more likely to die and not reproduce.
- So the better-adapted individuals have a better chance of passing on their features to the next generation through reproduction. This means that, in the next generation, there will be more individuals with the better-adapted variations in features.

Example of natural selection

In any population of organisms, such as a species of flower in a field, there will be variation in characteristics as a result of the variation in their alleles. For our example, let's consider height in sunflowers.



Δ Fig. 11.15 Taller plants are better adapted to receiving more sunlight on their leaves.

- Some individual plants of this species will grow taller than others, as a result of variation in the alleles of their genes (see Fig. 11.15).
- Taller plants grow their leaves higher up the stalk, capturing more sunlight for photosynthesis and shading shorter plants so that those get less sunlight.

- So taller plants are able to make more food, and therefore make more seed than shorter plants.
- Embryos in the seeds from the tall plants will have inherited the 'tallness' alleles from the parent plants.
- There will be more seed with 'tallness' alleles, so when they germinate there is likely to be a greater proportion of tall plants in the next generation.
- Over more generations, the height of this species of plant in this area will increase because taller plants are more likely to survive and reproduce than shorter plants.

It is a factor of the environment (light intensity) that has caused this change in the population. We call this *natural selection*, because a natural factor appears to select individuals with some characteristics rather than others, making it possible for them to pass on their genes to the next generation more successfully.

EXTENDED

Evolution

If the environment does not change, selection does not change. This will favour individuals with the same characteristics as the parents. If the environment changes, or a mutation produces a new allele, selection might now favour individuals with different characteristics or with the new allele. So the individuals that survive and reproduce will have a different set of alleles which they pass on to their offspring. This will bring about a change in characteristics of the species – in other words, it will produce **evolution**.

REMEMBER

Natural selection gives some individuals a survival or reproductive advantage over others with different characteristics. When describing the stages in evolution of a species by natural selection, make sure you identify why each new development gives the organism an advantage over those individuals that have not changed.

Evolution means 'change over time' – in terms of organisms, it usually means how species change in their adaptive features over time as a result of natural selection. Usually this takes hundreds, thousands or even millions of years, making it difficult to see evolution in action.

Dinosaurios con plumas

Δ Fig. 11.16 Reconstruction of a dinosaur with feathers, from fossil evidence.

Evidence from the fossil record is helpful in talking about evolution. For example, over 100 million years ago some species of dinosaur evolved feathers to provide insulation of the skin over the whole body. Some longer feathers also possibly evolved for display, to attract a mate. Over time, some species of feathered dinosaur evolved larger forelimbs, with longer feathers, possibly to help them glide to escape predators. From these, the first birds evolved strong wing muscles that allowed them to fly.

Antibiotic resistance in bacteria

Natural selection results in a *process of adaptation,* which means that over generations those features that are better adapted to the environment become more common. This means populations of organisms become better suited to their environment. An example is the development of antibiotic resistance by bacteria.

Antibiotics are chemicals that are used to kill bacteria when they cause infection. The first antibiotic that was developed was penicillin. Antibiotics were first used widely to treat injured soldiers during the Second World War and, since then, have saved millions of lives. However, more recently, the evolution of bacteria that are resistant to antibiotics has become a major problem, causing many human deaths from infections each year.

The evolution of antibiotic resistance is a good example of evolution through natural selection. It happens like this:

- a patient suffering from a bacterial infection is treated with an antibiotic, for example penicillin
- the bacterial infection is caused by millions of bacteria of one species, and the individual bacteria within that population show variation
- some bacteria, as a result of random mutation, may have an allele for a new characteristic that means the penicillin doesn't kill them as quickly as the other bacteria – we say these bacteria have developed **antibiotic resistance**
- unless the full course of antibiotics is taken, the few that are more resistant will survive and reproduce
- the number of resistant bacteria in the patient may increase to such a level that the resistant bacteria escape from the body and are passed to another person
- the newly infected person, if they become ill as a result of the infection, cannot be treated with penicillin because it will not kill the resistant bacteria; so the doctor will have to use a different antibiotic to control the infection.

Over time, some bacteria have developed resistance to a large range of antibiotics, and many species show multiple resistance – resistance to many kinds of antibiotics. Now, there are very few new antibiotics to use on multiple-resistant types of bacteria, and doctors are concerned that there will be an uncontrollable increase in the number of deaths from bacterial infections that used to be treatable.

The rate of evolution of a new variation of a characteristic is related to how well it is favoured by natural selection. Antibiotics are an example of a *strong selecting factor* – only those bacteria that are most resistant to them will survive and the rest will die. So evolution of antibiotic resistance happens quickly.

END OF EXTENDED

QUESTIONS

1. Define *natural selection* in your own words.
2. Explain the importance of the following factors in natural selection:

   a) variation in the population, **b)** competition, **c)** adaptive features.
3. EXTENDED Explain how natural selection results in populations becoming better suited to the environment.
4. EXTENDED Draw a diagram, such as a cartoon strip, to explain how antibiotic resistance develops in a bacterial species.

Selective breeding

Selective breeding (also known as *artificial selection*) is when a breeder chooses which parent organisms to breed together. The choice is usually for desirable features, such as those that have economic importance. Examples include increasing the size of farm animals kept for meat, and increasing egg size in chickens. It may be done for other reasons too, such as to develop breeds of dogs that make good pets, or to produce new colours of flowers in plants grown for horticulture.

As many characteristics are controlled by genes, by breeding together organisms that show the nearest form to a desired characteristic the breeder is more likely to get offspring that also have the desired characteristic (such as large size). If the breeder continues to select individuals with the largest size (say), over time the average size of the organisms will increase. Artificial selection may also be done to combine particular multiple characteristics.

EXTENDED

Natural selection versus artificial selection

In artificial selection humans decide on the characteristics they want from a species and then select the individuals closest to those characteristics to reproduce. Over a few generations of choosing individuals with the necessary characteristics, humans can develop organisms with their chosen traits, such as better milk production in cows, or larger flowers in roses.

In natural selection the results are more unpredictable, because the individuals that are best adapted to their environment are selected. Those individuals that are best adapted have more offspring and so, over time, the species develops characteristics that help them adapt to the environment. This means that the results of artificial selection are more useful to humans, whereas the results from natural selection are better adapted to the environment.

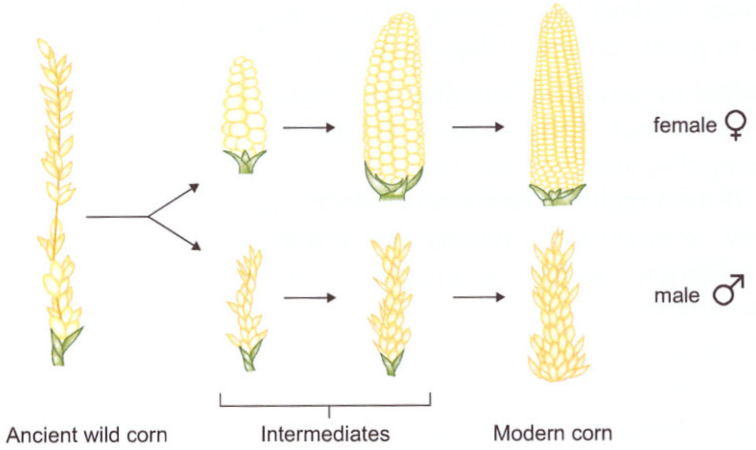
Example of selective breeding

One example of the improvement of a crop plant is the breeding of wheat plants to develop a variety that has a large seedhead (that gives lots of grain, which we use for food) but a short stalk (which means the plant wastes less energy in producing parts that we don't use, but also helps to support the large seedhead better in strong winds).

The plant breeders start by crossing a wheat plant with a long stalk and a large seedhead with a wheat plant that has a short stalk and small seedhead; there may be some offspring with the advantageous combination of short stalk and large seedhead. Selecting from the offspring that have the best combinations of these characteristics over many generations can produce a new variety with the perfect combination of these characteristics.

REMEMBER

You can check your understanding by explaining the inheritance of characteristics through selective breeding in terms of the inheritance of genes and alleles that you have already learned.



Δ Fig. 11.17 Over centuries of selective breeding, the ancient wild corn (maize) has developed into the modern breeds of corn that have the large seed cobs that we harvest.

The same process can be done with domesticated animals, by breeding together individuals that show the best features, to produce new breeds. It too can take many generations to improve the animal breed, and it can take longer than with plants, as animals generally take longer to become mature enough for reproduction.

Note that plants of the same species but with distinctively different characteristics are called **varieties**, whereas animals of the same species with distinct characteristics are called *breeds*. As they are still of the same species, different plant varieties can interbreed and different animal breeds can interbreed.

SCIENCE IN CONTEXT

TULIP MANIA

Plants are also bred in horticulture, for gardens, for houseplants and cut flowers, to improve the colour, shape and form of the flowers and leaves. This is because people like new things.

For example, tulips were introduced to Europe in the 1500s from Turkey. They were so exotic that they became a luxury item that all wealthy people had to have. Plant breeders rapidly developed new varieties through selective breeding, such as flowers with different-coloured lines or specks on the petals.

At the peak of 'tulip mania' in the Netherlands in the 1630s, single tulip bulbs were being sold for more than 10 times the annual income of a skilled craftsperson. Prices suddenly collapsed in 1637, mainly because people got bored with tulips.

Δ Fig. 11.18 A completely black flower is almost impossible to breed, but that doesn't stop people wanting to try to produce it because many people would pay a lot of money for something so rare.

QUESTIONS

1. Who carries out selective breeding, and why?
2. Give two examples of selective breeding.
3. Describe the process of selective breeding.
4. EXTENDED Describe the difference between *natural selection* and *selective breeding*.

End of topic checklist

Key words

adaptive feature, antibiotic resistance, continuous variation, discontinuous variation, evolution, gene mutation, genetic variation, ionising radiation, mutagen, mutation, natural selection, phenotypic variation, selective breeding

During your study of this topic you should have learned:

○ Variation is the differences between organisms of the same species.

○ **EXTENDED** Phenotypic variation in characteristics in a species may be caused by genes, environment or a combination of the two.

○ Continuous variation produces a range of phenotypes between two extremes.

○ Discontinuous variation produces a limited number of distinct phenotypes with no intermediates.

○ **EXTENDED** Mutation is a change in a gene or chromosome.

○ **EXTENDED** The rate of mutation can be increased by ionising radiation (such as gamma rays, X rays and ultraviolet radiation), and by chemical mutagens (such as the chemicals in tobacco smoke).

○ Natural selection is the struggle for survival between individuals in a population for limited resources, which results in the better-adapted organisms having a greater chance of surviving, reproducing and passing on their features to the next generation.

○ **EXTENDED** Evolution is the change in adaptive features of a population over time as the result of natural selection.

○ **EXTENDED** Antibiotic resistance in bacteria is an example of evolution by natural selection.

○ Selective breeding can change the characteristics of domesticated animals and crop plants to produce varieties with economic importance.

End of topic questions

Note: The marks given for these questions indicate the level of detail required in the answers. In the examination, the number of marks given to questions like these may be different.

1. In a student class, a survey was carried out of the variation shown in some features.

a) Of the 35 students, 28 were able to roll their tongue and 7 could not. There were no students who could partly roll their tongue. Which type of variation does tongue-rolling show? Explain your answer. **(2 marks)**

b) Describe another type of variation in humans, and give an example. **(2 marks)**

c) Explain how this type of variation differs from the type shown by tongue-rolling. **(1 mark)**

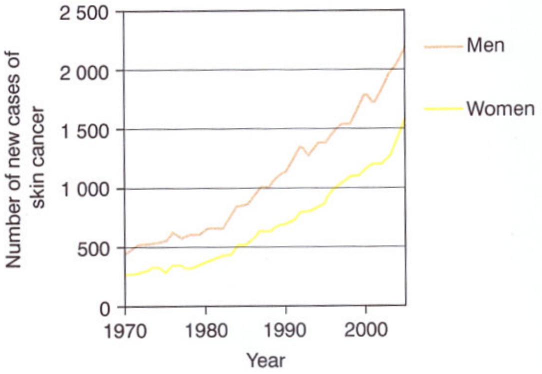
2. Skin cancer is the most common form of cancer in light-skinned people. The majority of skin cancers are not life threatening if treated early.

a) Cancer may be caused by a mutation to a gene in a cell. What does *mutation* mean? **(1 mark)**

b) Name two types of causes of mutation. **(2 marks)**

c) What is the most likely cause of skin cancer? Explain your answer. **(2 marks)**

d) The graph in Fig. 11.19 shows the number of new cases of skin cancer in Sweden between 1970 and 2005.



∆ Fig. 11.19 Cases of skin cancer in Sweden over the last 40 years.

(i) Describe the curves shown on the graph. **(2 marks)**

(ii) Suggest one possible reason for the trend shown in both curves. Explain your answer. **(2 marks)**

3. Polar bears are the largest predator in northern polar regions. They particularly hunt seals, which have good eyesight.

a) Describe one adaptive feature of the polar bear that helps to increase their chances of catching seals. Explain your answer. **(2 marks)**

b) Describe one adaptive feature that helps them to survive in the cold conditions of the polar region. Explain your answer. **(2 marks)**

Δ Fig. 11.20 This polar bear is on the hunt for seals.

Human activity can have a huge impact on food chains and food webs, and even lead to the extinction of whole species. The introduction of just 24 wild rabbits into Australia in 1859 resulted in a rapidly spreading population that has decimated huge areas of diverse environments, causing havoc to native animal and plant species. Various attempts to keep the rabbit population in Australia in check have been attempted, for example by introducing the rabbit disease myxomatosis. Even so, scientists estimate that rabbits still cost Australian farmers more than $200 million annually in lost production, in addition to the ongoing damage that they wreak on the natural environment.

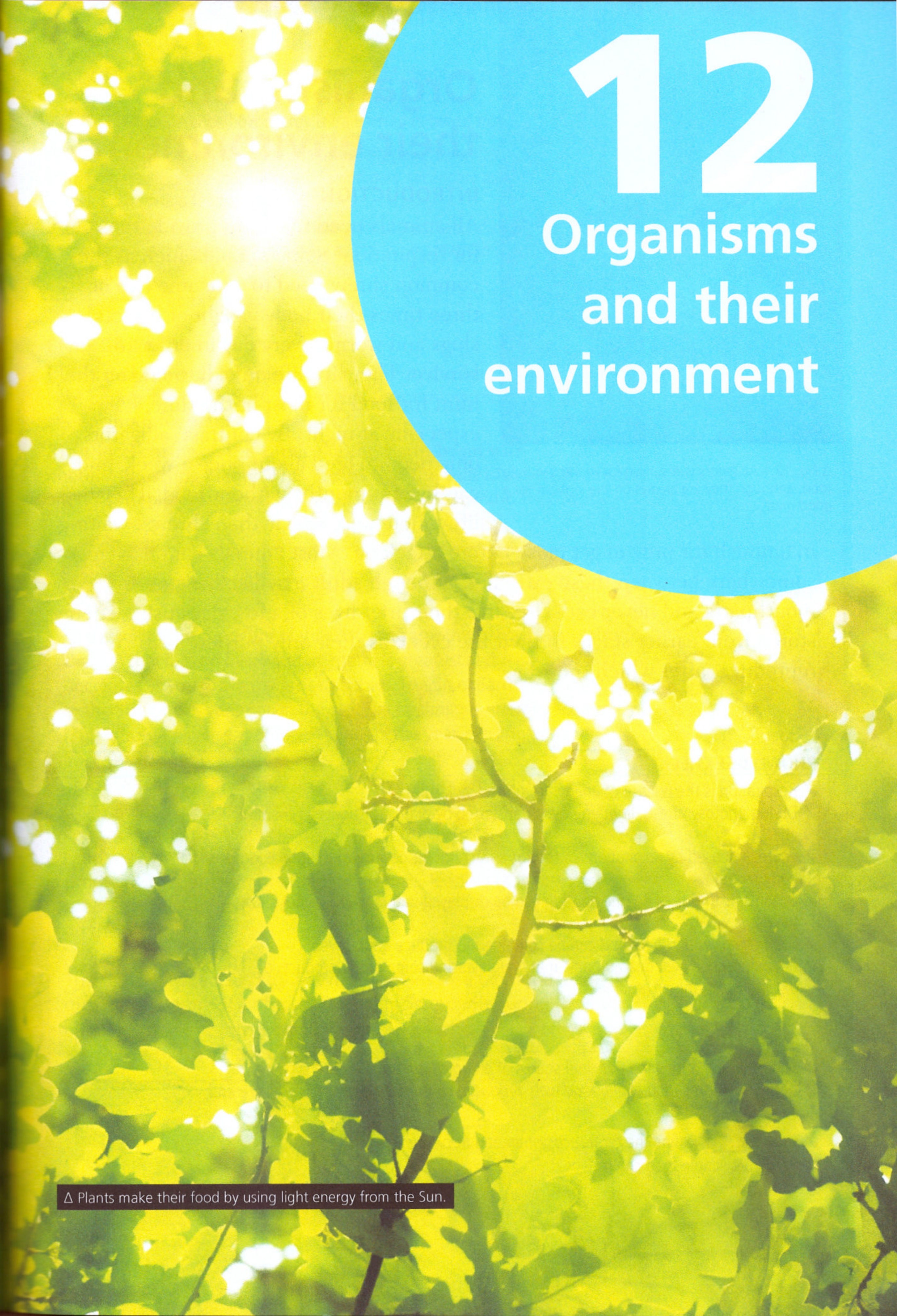
CONTENTS

a) Energy flow

b) Food chains and food webs

12

Organisms and their environment



Δ Plants make their food by using light energy from the Sun.

∆ Fig. 12.1 Alligators can survive for months without food, although they are always on the lookout for a good meal.

Organisms and their environment

INTRODUCTION

All animals need to eat, to provide the fuel for respiration. Some animals such as the common shrew need to consume two or three times their body weight of insects, slugs and worms every day in order to survive. They live life quickly, being on the hunt for food for most of the time, especially at night. By contrast, alligators only need to feed about once a week, and can live for months without food. They live life much more slowly than shrews, waiting in ambush for prey to get close before attacking. Most animals eat on average somewhere between these extremes, although adult mayflies have no mouthparts and never eat. They live their brief lives of a few days using energy stored from earlier stages in their life cycle, as their only purpose is to reproduce, after which they die.

KNOWLEDGE CHECK

✓ Respiration is the release of energy from food molecules.
✓ During photosynthesis, light energy is transferred by plants to sugars as chemical energy.
✓ Energy released by respiration is used for a range of purposes, including making new body tissue.
✓ Organisms that feed on one another can be displayed in a food chain that shows who eats what.
✓ Food chains within a habitat can be combined to produce a food web.
✓ Decomposers digest dead organic material, releasing some of the products of digestion into the environment.

LEARNING OBJECTIVES

✓ State that the Sun is the principal source of energy input to biological systems.
✓ Define the terms *food chain, food web, producer, consumer, herbivore, carnivore* and *decomposer*.
✓ **EXTENDED** Define the terms *ecosystem* and *trophic level*.
✓ Construct simple food chains.

- ✓ Interpret food chains and food webs in terms of identifying producers and consumers.
- ✓ **EXTENDED** Describe how energy is transferred between trophic levels.
- ✓ **EXTENDED** Explain why food chains usually have fewer than five trophic levels.
- ✓ State that consumers may be classed as primary, secondary and tertiary, according to their position in a food chain.
- ✓ **EXTENDED** Identify producers, primary consumers, secondary consumers, tertiary consumers and quaternary consumers as the trophic levels in food webs and food chains.

ENERGY FLOW

Plants make their food (sugars) from carbon dioxide and water using light energy from the Sun. In systems terminology, sunlight is the energy input for plants.

Most food chains on the surface of the Earth begin with photosynthesising plants. This means that the Sun is the main input of energy into biological systems, such as food chains and food webs.

SCIENCE IN CONTEXT

ENERGY INPUT FROM THE SUN

As a result of the curvature of the Earth, the amount of light energy from the Sun that falls on every square metre is greatest at the Equator, and decreases as you move towards the poles. The tilt of Earth's axis in relation to the Sun causes variation in the amount of sunlight energy received by high-latitude regions at different times of the year, causing seasons.

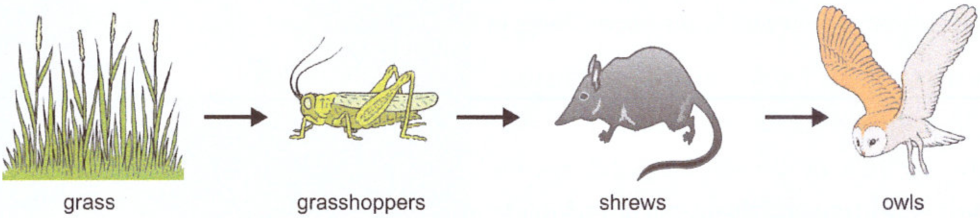
These differences in energy received have major effects on the ecosystems in each region. Parts of the world near the Equator that receive sufficient rainfall, such as tropical rain forests, have a greater productivity of plants in a year than other regions. This greater productivity supplies more food for animals, leading to a greater productivity of animals – some of these areas are the most biodiverse on the planet.

The seasonal effects in high-latitude regions result in rapid plant growth in summer months and virtually no growth during the winter, although some of this effect is the result of lack of heat energy from the Sun as much as lack of light energy.

FOOD CHAINS AND FOOD WEBS

Food chains

You should be familiar with food chains from your earlier work. A **food chain** shows 'who eats what' in a habitat. For example, in Fig.12.2, owls eat shrews, shrews eat grasshoppers, grasshoppers eat grass. (Remember, the arrows in a food chain show the direction of energy flow.)



Δ Fig. 12.2 An example of a food chain.

Each level in a food chain shows a separate level at which that species is feeding.

- Grass – this is the **producer** level, because grass is a plant and produces its own food (organic nutrients) using light energy during photosynthesis. All food chains start with a producer level.
- Grasshoppers – these are the primary consumers, '**consumer**' because they eat the grass and 'primary' because they are the first eaters of other organisms in the food chain. This level may also be called **herbivores**, because they eat plant material.
- Shrews – these are consumers too, but they are specifically secondary consumers because they eat the primary consumers. They are also called **carnivores**, because they eat meat.
- Owls – these are also consumers, but they are specifically tertiary consumers because they eat the secondary consumers. They are also carnivores.
- Fungi and bacteria – these aren't shown in the food chain, but act as **decomposers** breaking down dead plants and animals. Fungi digest their food by secreting enzymes outside of the hyphae and absorbing the dissolved food materials. Many bacteria also do this.
- If anything ate owls, they would be quaternary consumers, but food chains often don't reach that level. Animals at the highest trophic level in a food chain may also be called the top consumers, or top predators. All animals are consumers, because they eat other organisms to get their food, in contrast to plants, which are producers.

◁ Fig. 12.3 The hyphae of this fungus are growing through the dead tree and secreting enzymes that cause the wood to break down into simpler chemicals.

The interactions in a given area, between all of the organisms and between the environment and the organisms, form a unit called an **ecosystem,** e.g a lake.

EXTENDED

Each feeding level of a food chain is called a **trophic level**. So producers are one trophic level, primary consumers (or herbivores) are the trophic level that feeds on producers, and so on. We also use the concept of trophic levels in food webs and **pyramids of numbers** or **pyramids of biomass**, as you will see later in this topic.

SCIENCE IN CONTEXT

OTHER PRODUCERS

Not all producers are plants, and not all producers use light energy. There are species, mainly bacteria, which produce their own food without the presence of light energy from the Sun. Instead, they get the energy they need for the formation of sugars from chemical reactions.

These bacteria are the source of food for food chains and webs that exist where there is no sunlight, such as deep in oceans and in underground caves. Be careful to avoid the statement that 'all life on Earth depends on the Sun', as this is an oversimplification and not totally accurate.

Energy in food chains

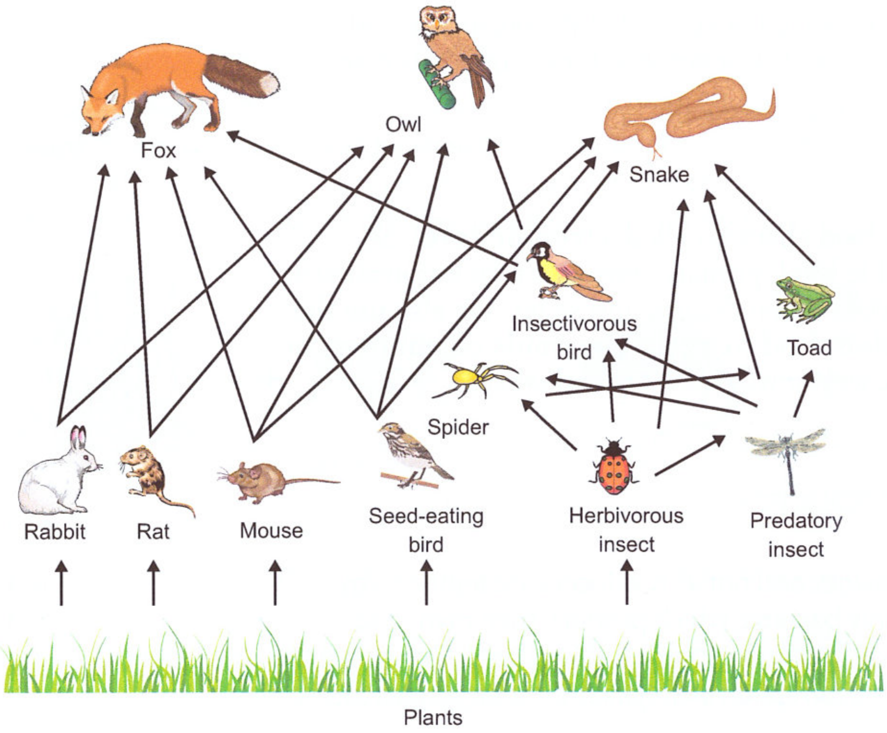
We can look at food chains in terms of energy. Plants use energy from light to build new substances. These substances act as stores of energy. A herbivore gains this store of energy, by ingestion, when it eats the plant. Some of that energy becomes stored in the substances in the animal's body, and so can be ingested by any animal that eats it. So we can define a food chain also as the transfer of energy between organisms by ingestion.

END OF EXTENDED

Food webs

If we look more closely at food chains, it is rare to find an organism that is eaten by just one other species, or a predator that feeds on just one type of prey. It may also be the case that a predator may feed on different kinds of organism – an **omnivore**, for example, is a primary consumer when feeding on plants, but a secondary or tertiary consumer when eating other animals. So food chains within a habitat are linked together to form a **food web**. A food web is a better description of the feeding relationships in a habitat and shows how living organisms are interconnected.

Food webs still usually group the organisms according to their feeding level. For example, in the simplified food web shown in Fig.12.4, the rabbit, squirrel, mouse, seed-eating bird and herbivorous insect are all primary consumers and are placed just above the producer level.



Δ Fig. 12.4 A simplified food web.

There are usually many more species in a habitat than shown in Fig.12.4, and linking them all in one web can get confusing. So food web diagrams may focus on the relationships between key organisms, rather than on all of them. For example, they may only include the most numerous species, or focus on the most vulnerable species. This can be helpful if you want to use the food web to predict what would happen to the ecosystem if the food web were changed in some way, such as by human activity.

You could use the food web shown to predict what would happen if the plants were sprayed with an **insecticide**. This would kill the herbivorous insects and so reduce the amount of food available to all the animals that feed on them.

QUESTIONS

1. Use your own words to define the following terms: *producer, consumer, herbivore, carnivore, decomposer*.
2. **EXTENDED** Use your own words to define the following terms: *ecosystem, trophic level*.
3. Name the principal source of energy to an ecosystem. Explain your answer.
4. Distinguish between a food chain and food web.
5. Describe how food webs can be (a) useful and (b) difficult to draw.

Energy transfers in biological systems

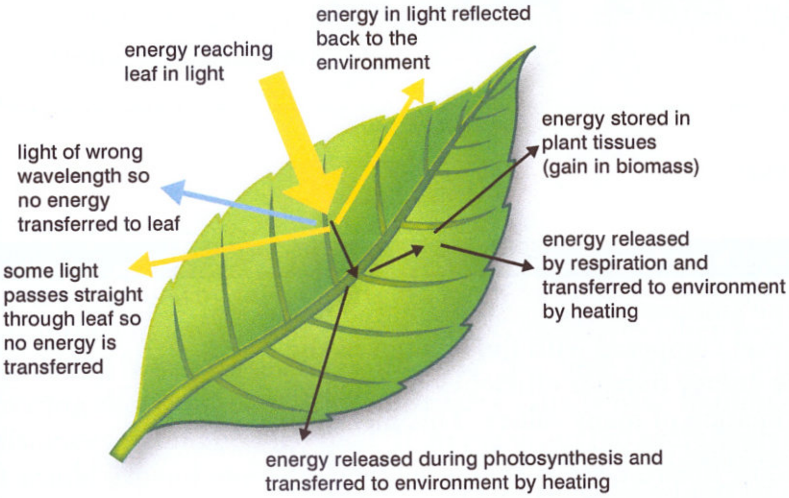
Plants transfer the energy from light into stored energy inside them. This energy is transferred to animals when they digest and assimilate plant food to make new substances in their body tissue.

The energy that a plant receives from light, or that an animal gets in its food, is always greater than the amount of energy it stores in the substances in its tissues. This is because some of the energy that it takes in is transferred to the environment in various forms. The energy losses from plants and animals differ in some ways.

Energy losses from plants

The amount of energy from sunlight that falls on the Earth's surface varies at different times of day and year, and varies in different parts of the world (with places near the Equator receiving more light energy than places nearer the poles). On average, tropical areas receive between 3 and 5 kWh/m^2 per day (which is about the same energy as a one-bar electric heater left on for 3–5 hours).

Plants use only a tiny proportion of this for many reasons, as shown in Fig.12.5. It has been estimated that most plants only transfer about 1% to 2% of the energy in the light that falls on them into chemical energy in their tissues (**biomass**). This is the energy available to a herbivore that eats the plant.


energy in light reflected back to the environment
energy reaching leaf in light
energy stored in plant tissues (gain in biomass)
light of wrong wavelength so no energy transferred to leaf
energy released by respiration and transferred to environment by heating
some light passes straight through leaf so no energy is transferred
energy released during photosynthesis and transferred to environment by heating

Δ Fig. 12.5 Energy gains and losses of a plant.

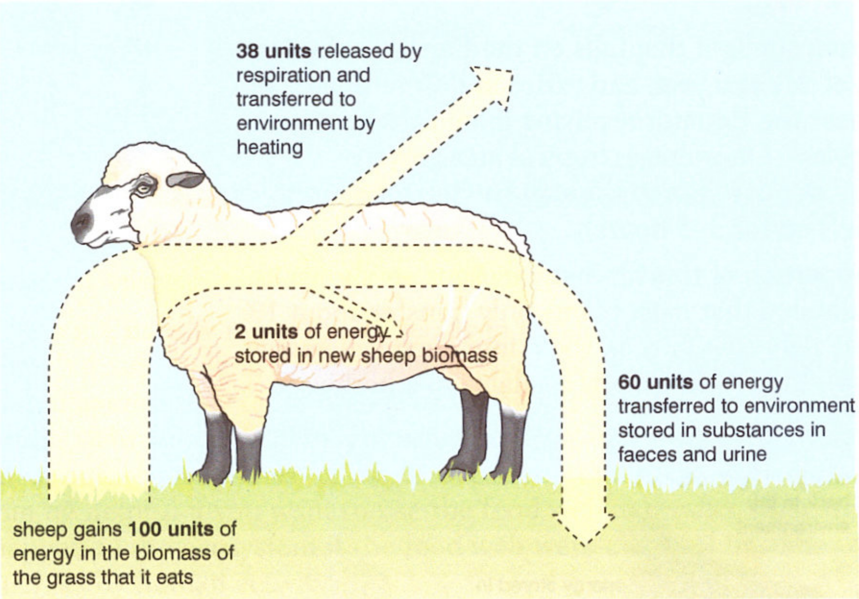
Energy losses in animals

When an animal eats, the food is digested in the alimentary canal and the soluble food molecules are absorbed into the body. The undigested and unabsorbed food in the alimentary canal is egested as faeces.

Absorbed food molecules may be used for different purposes in the body:

- to produce new animal tissue or gametes for reproduction
- as a source of energy for respiration
- converted to waste products in chemical reactions.

The energy stored in the food molecules may stay in the body stored in body tissue, or it may be transferred to the environment stored in waste chemicals such as urine. When food molecules are broken down during respiration and other reactions, some of the energy released from the molecules is transferred to the environment by heating, through the processes of conduction, convection and radiation. So only a small proportion of the energy stored in the animal's food is converted into energy stored in its body tissues as an increase in the animal's biomass.


38 units released by respiration and transferred to environment by heating
2 units of energy stored in new sheep biomass
60 units of energy transferred to environment stored in substances in faeces and urine
sheep gains **100 units** of energy in the biomass of the grass that it eats

Δ Fig. 12.6 The energy flow through a sheep.

REMEMBER

Energy transfer efficiency is the amount of energy stored in the body tissue at a particular trophic level compared with the amount in the previous level. Calculating the energy transfer efficiency between trophic levels involves the estimation of many values. This means that the transfer efficiencies you may find in textbooks and on the internet are only best estimates and must not be taken as exact.

In addition, many sources quote a value of 10% as the efficiency of energy transfer between any trophic level and the one above. Calculations of efficiency vary from about 0.2% to around 20% for different organisms in different ecosystems. This gives an *average* of 10%, but over such a large range this is not very reliable. It is better to prepare to explain how energy is gained and lost between trophic levels, in order to explain the shape of pyramids of energy and lengths of food chains, than to quote specific values for energy transfer efficiency.

QUESTIONS

1. Draw a flowchart to show the energy gains by and losses from a plant leaf.
2. Draw a flowchart to show the energy gains by and losses from a herbivore.
3. Explain why the amount of energy stored in an organism's tissues is always less than the amount of energy that it gained.

END OF EXTENDED

SCIENCE LINK

PHYSICS – ENERGY TRANSFER

- Food chains and webs describe which organisms consume others, but a key feature is that they show how energy is transferred from each trophic level to the next and this links to the law of conservation of energy.
- Energy ideas can be used to explain why the number of organisms in a predator trophic level are much lower than the number of organisms in the level below – energy transfers are never 100% efficient and not all energy is stored and available for the next level up.
- Energy ideas also indicate why food chains have a limited length – the useful energy is reduced to a point where an additional level could not be supported.

EXTENDED

The fact that there are energy losses to the environment at each trophic level explains why food chains are rarely more than four or five organisms in length. Any organism expends energy when looking for food, and the more scattered the food, the more energy is lost in moving about to find it. Top consumers usually have to hunt over large distances to find enough food. If an organism fed exclusively on them, it would expend more energy hunting for its food than it would gain from eating it.

END OF EXTENDED

End of topic checklist

Key words

carnivore, consumer, decomposer, ecosystem, food chain, food web, herbivore, omnivore, producer, trophic level

During your study of this topic you should have learned:

○ Producers are organisms that make their own organic nutrients (food), such as plants that use sunlight to produce sugars through photosynthesis.

○ Consumers are organisms that gain energy by feeding on other organisms. There are different levels of consumer, depending on their position in a food chain.

○ A herbivore is an animal that eats plants, and a carnivore is an animal that eats other animals.

○ A food chain shows the transfer of energy between organisms as a result of feeding, starting with a producer.

○ A food web is an interconnection of food chains that share some organisms.

○ A decomposer is an organism that gets its energy from dead or waste organic material.

○ **EXTENDED** A trophic level is a feeding level within a food chain, food web or pyramid of numbers or biomass.

○ **EXTENDED** Energy is gained at each trophic level as it is transferred from light in plants or from food in animals to make new body tissue.

○ **EXTENDED** Energy is transferred to the environment at each trophic level as heat energy from respiration, and also as chemical energy from animals in the form of faeces and urine.

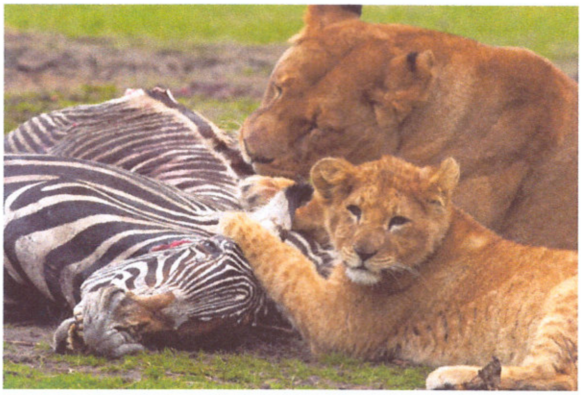
○ **EXTENDED** That a food chain is rarely more than five trophic levels in length because the top trophic level within the chain contains too little energy to support another trophic level.

○ **EXTENDED** An ecosystem is the community of organisms and the environment with which the organisms interact.

End of topic questions

Note: The marks given for these questions indicate the level of detail required in the answers. In the examination, the number of marks given to questions like these may be different.

1. The photograph in Fig.12.7 shows lions eating a dead zebra. Before the lions killed the zebra, the zebra had been feeding on grass.



Δ Fig. 12.7 Lions eating their kill.

a) Is the lion a carnivore or herbivore? Explain your answer. **(2 marks)**

b) At which level of a food chain does the zebra feed? **(1 mark)**

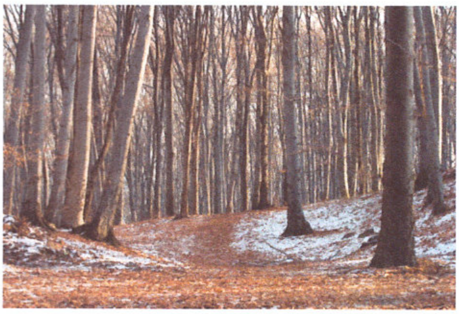
c) Draw a food chain for the organisms shown in the photograph. **(2 marks)**

d) Lions also feed on the herbivores gazelle and wildebeest. Use all these organisms to draw a food web for the African grassland. **(3 marks)**

2. **EXTENDED** In a tropical forest, the layer of dead leaves (called the leaf litter) on the forest floor is usually very thin at all times of the year. In temperate woodlands (where there are seasons), many trees drop their leaves in the autumn and grow new ones in the spring.

a) Tropical trees drop a few leaves at a time at any time of year. What happens to the leaves on the ground? Explain your answer as fully as possible. **(2 marks)**

b) The leaf litter in a temperate woodland is deep all through winter, when it may be cold enough for snow, until it gets warm again in spring. Then the leaf litter disappears. Explain these observations as fully as you can. **(3 marks)**



Δ Fig. 12.8 A temperate woodland in winter.

End of topic questions continued

3. Use the food web in Fig.12.4 to predict what would happen to the following species if all the herbivorous insects were killed by insecticide. Explain your answers.

   a) predatory insects **(2 marks)**

   b) insectivorous birds **(2 marks)**

   c) mice **(2 marks)**

   d) snakes **(2 marks)**

4. EXTENDED Explain as fully as you can why a food chain is unlikely to include more than five trophic levels. **(6 marks)**

5. EXTENDED Food chains in northern regions on Earth may be much shorter than food chains in tropical rain forests. Thinking only in terms of energy, try to explain this difference. **(4 marks)**

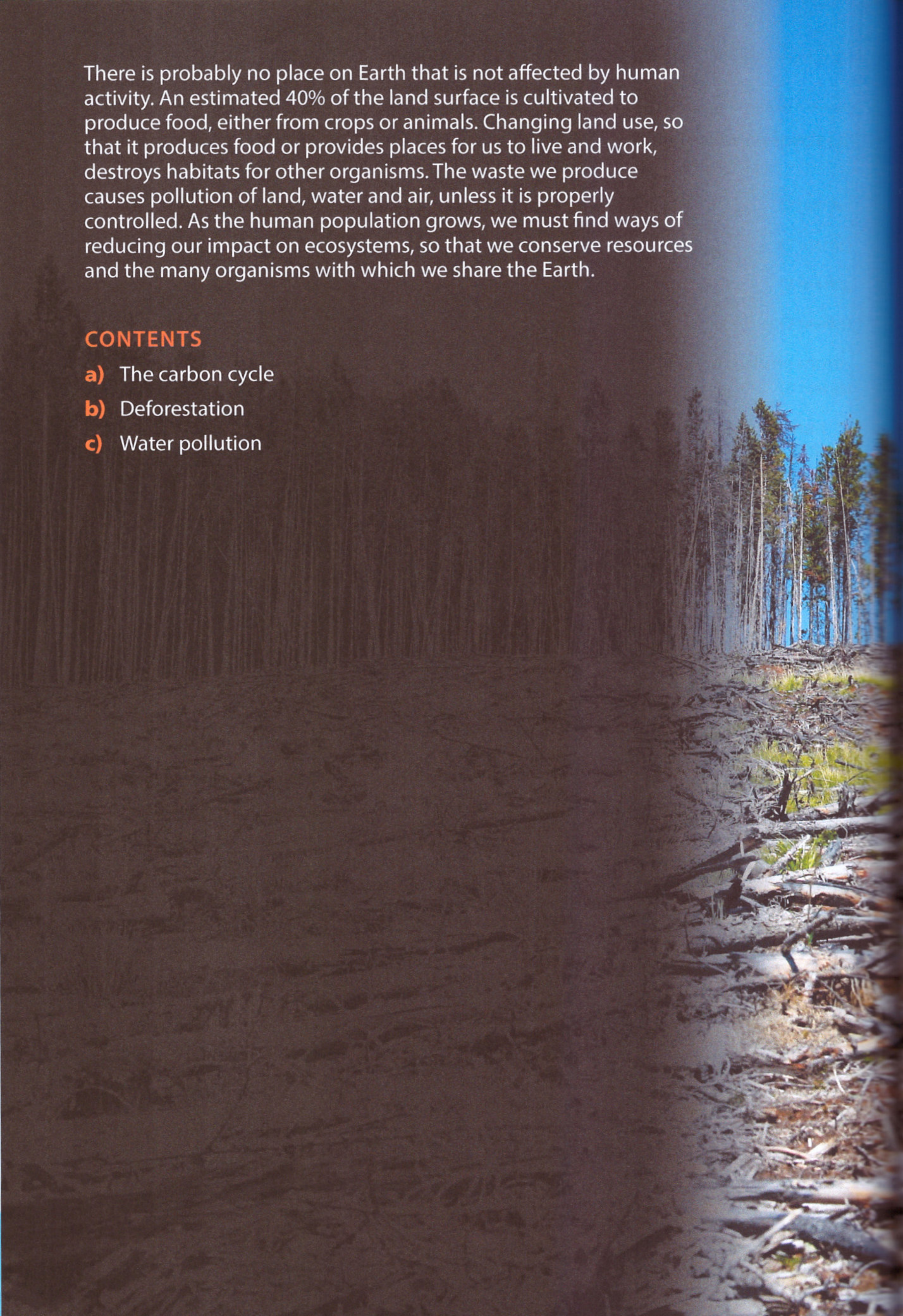
There is probably no place on Earth that is not affected by human activity. An estimated 40% of the land surface is cultivated to produce food, either from crops or animals. Changing land use, so that it produces food or provides places for us to live and work, destroys habitats for other organisms. The waste we produce causes pollution of land, water and air, unless it is properly controlled. As the human population grows, we must find ways of reducing our impact on ecosystems, so that we conserve resources and the many organisms with which we share the Earth.

CONTENTS

a) The carbon cycle

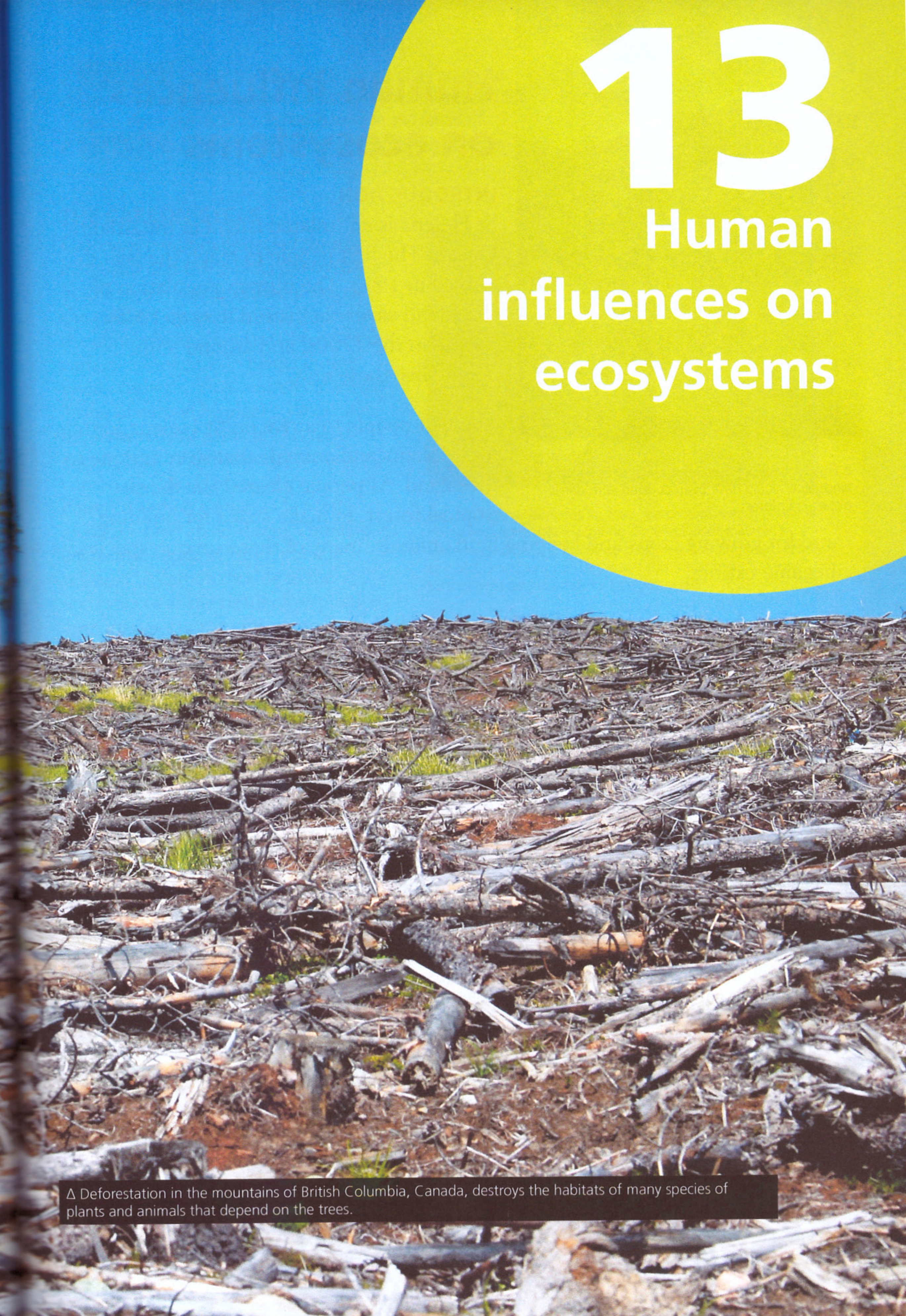
b) Deforestation

c) Water pollution

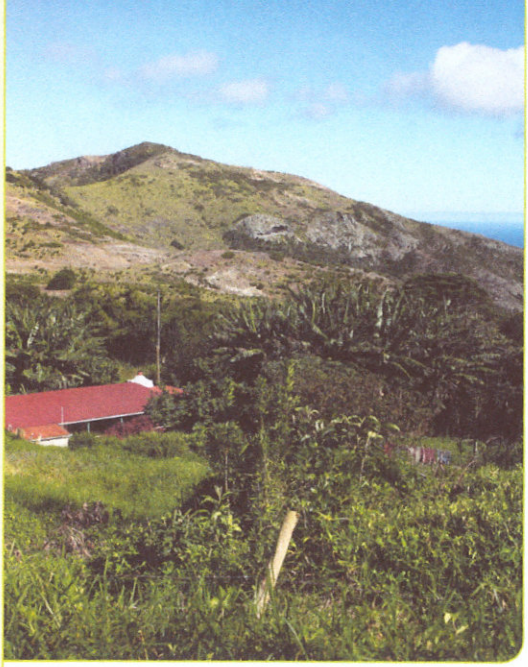


13

Human influences on ecosystems



Δ Deforestation in the mountains of British Columbia, Canada, destroys the habitats of many species of plants and animals that depend on the trees.



Δ Fig. 13.1 Before humans arrived on St Helena this landscape would have been covered with dense tropical rainforest.

Human influences on ecosystems

INTRODUCTION

St Helena is an isolated island in the Atlantic Ocean. The first people to reach the island arrived in 1502. The human population of the island slowly increased to over 1000 people in the 1700s, and around 4500 people live there now.

The first people to arrive on St Helena found many plants and animals that were unique to the island. As people cleared the dense tropical forest, to make space for building and for growing crops and keeping herd animals, many of these unique species became extinct.

The introduction of animals that didn't naturally live there, such as cats, goats and rats, also had a devastating effect on wildlife. Cats catch and kill small animals and birds, and rats steal and eat eggs from bird nests. Many of the lower areas near the sea are now completely bare of vegetation as a result of grazing by goats.

KNOWLEDGE CHECK

- ✓ Earth's atmosphere is affected by human activity (such as deforestation and combustion of fuels).
- ✓ The carbon cycle is a model of how carbon moves from living to non-living molecules through photosynthesis, respiration, feeding, decomposition, fossilisation and combustion.
- ✓ **EXTENDED** Combustion of fossil fuels and deforestation have contributed to an increase in carbon dioxide concentrations in the atmosphere.
- ✓ Deforestation causes many undesirable effects, such as habitat destruction, extinction, loss of soil, flooding and an increase of carbon dioxide in the atmosphere.
- ✓ Water can be polluted by chemical waste, discarded rubbish, untreated sewage and fertilisers.

LEARNING OBJECTIVES

- ✓ Describe the carbon cycle, involving photosynthesis, respiration, feeding, decomposition, fossilisation and combustion.
- ✓ **EXTENDED** Discuss the effects of the combustion of fossil fuels and the cutting down of forests on the oxygen and carbon dioxide concentrations in the atmosphere.
- ✓ List the undesirable effects of deforestation as an example of habitat destruction, including extinction, loss of soil, flooding and increase of carbon dioxide in the atmosphere.

- ✓ **EXTENDED** Explain the undesirable effects of deforestation on the environment.
- ✓ State the sources and effects of pollution of rivers, lakes and the sea by chemical waste, discarded rubbish, untreated sewage and fertilisers.
- ✓ **EXTENDED** Explain the process of eutrophication of water.

THE CARBON CYCLE

Carbon is continually cycled through the living and non-living parts of ecosystems, in different forms at different stages of the **carbon cycle**. Carbon dioxide from the atmosphere is converted to complex carbon compounds in plants during photosynthesis. This is often called the 'fixing' of carbon by plants. Respiration in plants returns some of this fixed carbon back to the atmosphere as carbon dioxide. Carbon in the form of complex carbon compounds passes along the food chain through feeding. At each stage, some of this carbon is released as carbon dioxide to the atmosphere as the result of respiration.

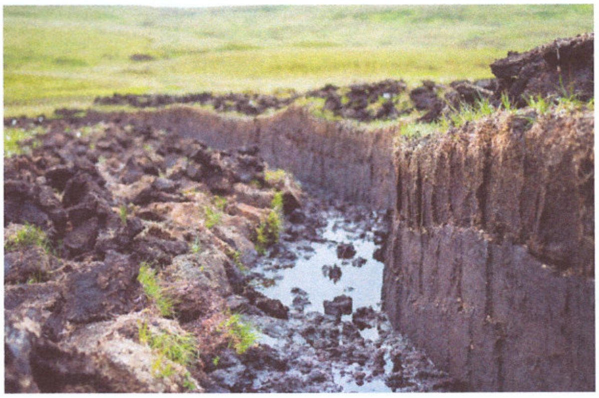


Fig. 13.2 Water excludes air from the ground, which prevents decay organisms from respiring. So dead plant material in waterlogged ground builds up over time, forming peat. Peat can be burned as a fuel, although this is being discouraged so that peat bog habitats can be protected.

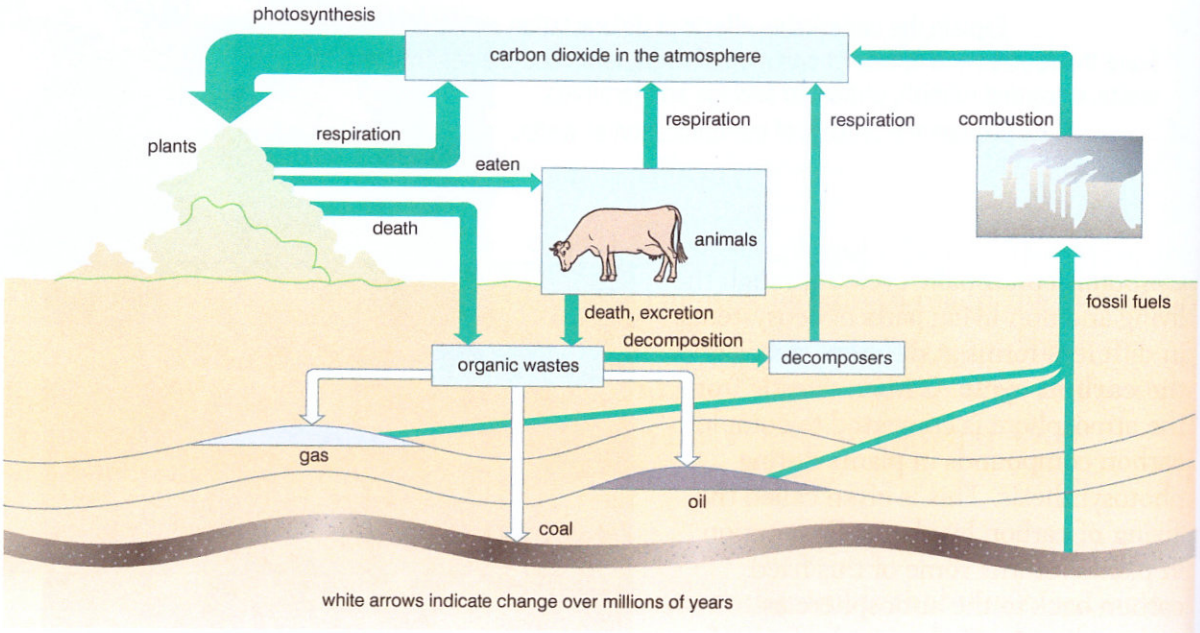
When organisms die, their bodies decay as they are digested by decomposers. Some of the complex carbon compounds are taken into the bodies of the decomposers, where some may be converted to carbon dioxide during respiration. Carbon dioxide may also be released directly into the atmosphere during decay.

Combustion

If dead organic material is buried too quickly by sediment or water for decomposers to cause decay, and remains buried, then it may be converted to other complex carbon compounds. Peat is formed when mosses and other plants are buried in swampy ground for hundreds of years. Over many millions of years, where there were once huge forests growing in swampy regions, heat and pressure have turned the organic material into coal. Heat and pressure over many millions of years also produces oil from the decaying bodies of tiny marine organisms that were buried in sediment at the bottom of oceans. Peat, coal and oil are **fossil fuels**. We can release the carbon from the complex carbon compounds in fossil fuels into the air as carbon dioxide during **combustion**, when we burn them.

REMEMBER

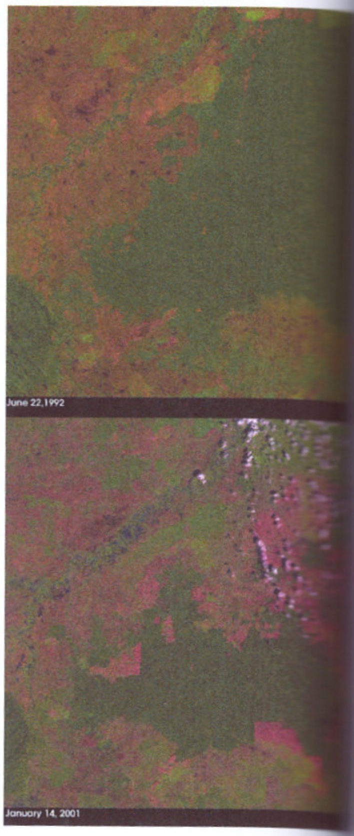
Make sure you are certain what form carbon is in (carbon dioxide or complex carbon compounds, such as carbohydrates) at each stage of the carbon cycle.


photosynthesis
carbon dioxide in the atmosphere
plants
respiration
respiration
respiration
combustion
eaten
death
animals
death, excretion
decomposition
organic wastes
decomposers
fossil fuels
gas
oil
coal
white arrows indicate change over millions of years

Δ Fig. 13.3 A summary of the carbon cycle.

DEFORESTATION

Deforestation is the permanent destruction of large areas of forests and woodlands. It usually happens in areas that provide quality wood for furniture and to create farming or grazing land. Deforestion results in a loss of habitat for many species, which can often lead to extinction. Once the forests have gone there is a greater risk of flooding and the top layer of soil can also be lost.


June 22, 1992
January 14, 2001

Δ Fig. 13.4 Satellite images of the island of Sumatra show the exte deforestation between 1992 (top photo, land mostly green) and 20

EXTENDED

Forests act as a major carbon store because carbon dioxide is taken up from the atmosphere during photosynthesis and used to produce the chemical compounds that make up the tree. When forests are cleared, and the trees are either burned or left to rot, this carbon is released quickly into the air as carbon dioxide. This rapidly increases the proportion of carbon dioxide compared with oxygen in the air surrounding the forest. In addition, the amount of oxygen removed from the local atmosphere by plants for photosynthesis may also drop, changing the balance between carbon dioxide and oxygen in the atmosphere locally.

On the scale of deforestation in the Amazon Basin, the amount of carbon dioxide released is so great that it cannot be brought back into balance as a result of photosynthesis. This additional carbon dioxide remains in the atmosphere.

Over the past 10 000 years or so, as a result of photosynthesis and respiration and other physical processes, the exchange of carbon between organisms and the atmosphere resulted in little change in the amount of carbon dioxide in the atmosphere. On average, over one year, about 120 billion tonnes of carbon dioxide are removed from the atmosphere by photosynthesis, and a similar amount is returned by respiration.

During the past 250 years, however, combustion of forests and fossil fuels as a result of human activity has added increasing amounts of CO_2 to the atmosphere. Today about 5.5 billion tonnes of carbon dioxide are added to the atmosphere every year through human activity, particularly through combustion of fossil fuels.

Compared with 120 billion tonnes through natural processes, this may not seem a lot, but there is no process that balances this addition. So the concentration of carbon dioxide in the atmosphere is increasing. It is this additional carbon dioxide in the atmosphere that most people believe is causing global warming and climate change.

QUESTIONS

1. Describe the role of the following in the carbon cycle:

a) respiration, **b)** photosynthesis, **c)** decomposition.

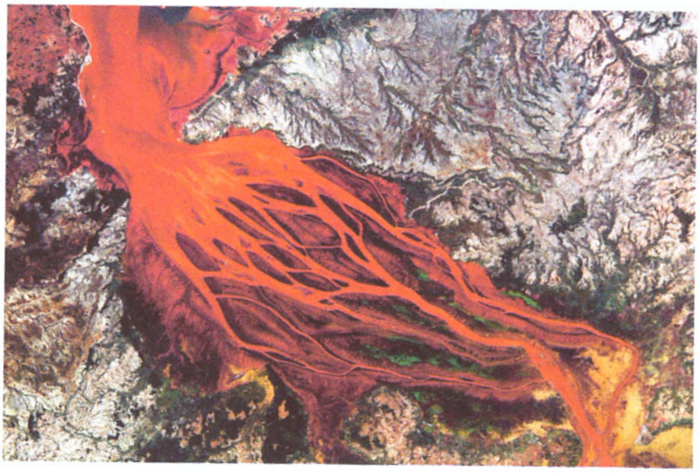
2. In what form is carbon when it is in the following stages of the carbon cycle?

a) Earth's atmosphere, **b)** plant tissue, **c)** fossil fuels

3. EXTENDED Describe the effect of large-scale deforestation on the oxygen and carbon dioxide concentrations of the atmosphere.

Deforestation also has an effect on the **water cycle**. Trees draw ground water up through their roots and release it into the atmosphere by transpiration. As forest trees are removed, the amount of water that can be held in an area decreases, which in turn can cause either increasing or decreasing rainfall in the area.

Removing the protective cover of vegetation from the soil can also result in **soil erosion**. This is where the soil is washed away by rain. The top layers of soil are the ones that contain the most nutrients, from the decay of dead vegetation, so soil erosion removes essential nutrients from the land. Soil nutrients are also lost by **leaching**, which is the soaking away of soluble nutrients in soil water, because there are few plant roots in the soil to absorb the nutrients and lock them away in plant tissue. This loss of nutrients from the soil is permanent, and makes it very difficult for forest trees to regrow in the area, even if the land is not cultivated.



◁ Fig. 13.5 This satellite image of a river estuary in Madagascar shows large amounts of soil in the water (orange). This is a result of deforestation near the river.

Loss of plant species due to deforestation will result in a loss of animal species in the same **community**, because of their feeding relationships in the food web. Many tropical rainforests are areas of high **biodiversity**, where many organisms live. They also contain many species found nowhere else, because they have evolved together in an energy-rich and relatively unchanging environment. Destruction of tropical rainforests, such as in the Amazon Basin, is causing a high rate of extinction of species.

END OF EXTENDED

QUESTIONS

1. Give two causes of habitat destruction as a result of human activity.

2. EXTENDED Explain these terms:

a) *deforestation*

b) *soil erosion*

c) *leaching*.

3. EXTENDED Explain how deforestation may affect:

a) the water cycle

b) soil fertility

c) atmospheric carbon dioxide.

SCIENCE LINK

CHEMISTRY – CHEMICAL REACTIONS

- The carbon cycle connects together a number of chemical reactions, each of which can be described in terms of particles and by using word equations and symbol equations.
- Combustion (reacting with oxygen) leads to a number of processes, which impact on the environment and the organisms that can survive in a particular habitat, such as **acid rain** and the production of carbon dioxide.
- Since many aspects of an ecosystem are interconnected, human activity in one situation (such as using fertilisers or burning fuels to provide energy) can have an impact in a much wider range of situations and contexts.

REMEMBER

In your exams, you may be given examples of ecosystems that have been damaged, polluted or conserved other than the ones discussed in this topic. You will be expected to apply the principles you have learned here to the examples you are given.

WATER POLLUTION

Pollution is the adding of substances to the environment that cause harm. Many human activities can lead to pollution of water, land and air.

Discarded rubbish

Plastics are used to make a huge number of products. Many of these plastics are **non-biodegradable**, which means that they cannot be decayed by the action of decomposers such as fungi and bacteria. If left in the environment, they may remain there unchanged for tens, or even hundreds, of years.

Plastic that gets into water systems may end up out at sea, where it collects in huge areas, commonly called 'garbage patches', where the oceans circulate.

Δ Fig. 13.6 Much of the pollution in oceans and on sea shores is caused by discarded plastic.

The plastic is a form of pollution because:

- plastic bags may be swallowed by animals such as turtles that mistake them for their prey, jelly fish
- plastic nets and ropes may entangle organisms, so that they die of starvation

- the plastic may be broken down to release toxins that affect organisms in the area
- the plastic may break down into small particles, called nurdles, which are swallowed by animals that mistake them for food.

Research has shown that at least 267 species worldwide have been affected by plastic marine debris.

QUESTIONS

1. Describe two problems with the decay of non-biodegradable plastics.
2. Explain why non-biodegradable plastics are causing pollution in oceans.

Untreated sewage

Pollution of rivers, lakes and seas may also be caused by the addition of chemicals, from farming, human waste or from chemical production.

Sewage is human waste, faeces and urine, which we all produce and need to dispose of. Faeces and urine contain high concentrations of many nitrogen-containing substances, and so are good sources of nutrients for plants and microorganisms. In fact, farmers often use animal waste as manure to spread on their fields to increase crop production.

In areas where many people live, sewage disposal is a big problem. Many cities have sewage management systems, to carry the sewage in pipes to treatment centres where it can be broken down, or far from the city.

Δ Fig. 13.7 In some fast-growing cities there are no proper systems for removing and treating sewage.

When untreated sewage is added to water, the nutrients in it dissolve into the water. This leads to eutrophication (see below) and, like the addition of artificial fertilisers to water, can increase plant and algal growth, resulting in an increase in bacterial growth, a fall in oxygen concentration in the water, and death of aquatic organisms. In addition, human waste contains many bacteria, some of which can cause infection, leading to vomiting, diarrhoea, fever and even death.

Even when sewage is treated properly to reduce the amount of nutrients it contains, and to remove pathogens, it may still contain concentrations of some substances that can cause harm to organisms. Female sex hormones are used in the contraceptive pill. Women taking these pills excrete the hormones in their urine. Sewage treatment breaks down some of the hormones, but tiny amounts may be left in the water that is returned to the natural water systems, such as rivers.

These tiny amounts can affect other animals. For example, some male fish in these rivers have a reduced sperm count and may even produce eggs instead of sperm. This is known as **feminisation** of males, as the males show female features. There is also a concern that drinking water taken from these rivers may contain sufficient concentrations of the hormones to affect men and reduce their sperm count.

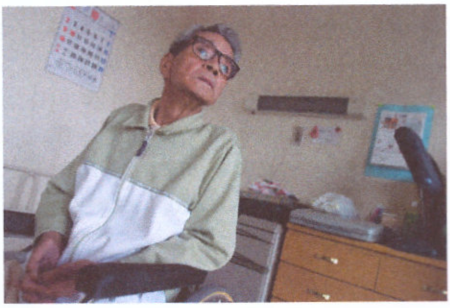
Chemical waste

Water pollution can be caused by other substances. Many industries produce liquid waste that is easiest to dispose of into water systems. In most places there are strict laws about what can and cannot be released into rivers, streams and lakes. Some substances, like sewage, lead to eutrophication. Others are toxic, such as the metals copper, mercury and lead and some organic chemicals. These must be cleaned completely from any waste water that drains into water systems. This is to prevent the toxins being absorbed by plants and animals, and passing into food chains where they can cause damage.

SCIENCE IN CONTEXT

THE MINAMATA POLLUTION DISASTER

One of the worst water pollution incidents occurred in Japan between about 1932 and 1968. A chemical factory released a mercury-containing chemical into Minamata Bay in waste water from the industrial processes. In the bay, shellfish and fish absorbed the mercury. When people ate the shellfish and fish, the mercury was absorbed and stored in their bodies. Over 10 000 people eventually absorbed so much mercury that it caused many different kinds of damage to them, including to muscles, nerves, vision and speech. Over 2000 people died as a direct result of the mercury.



Δ Fig. 13.8 Taisuke Mitarai, 69 years old, suffers the effects of mercury poisoning as a result of the Minamata disaster.

Fertilisers and eutrophication

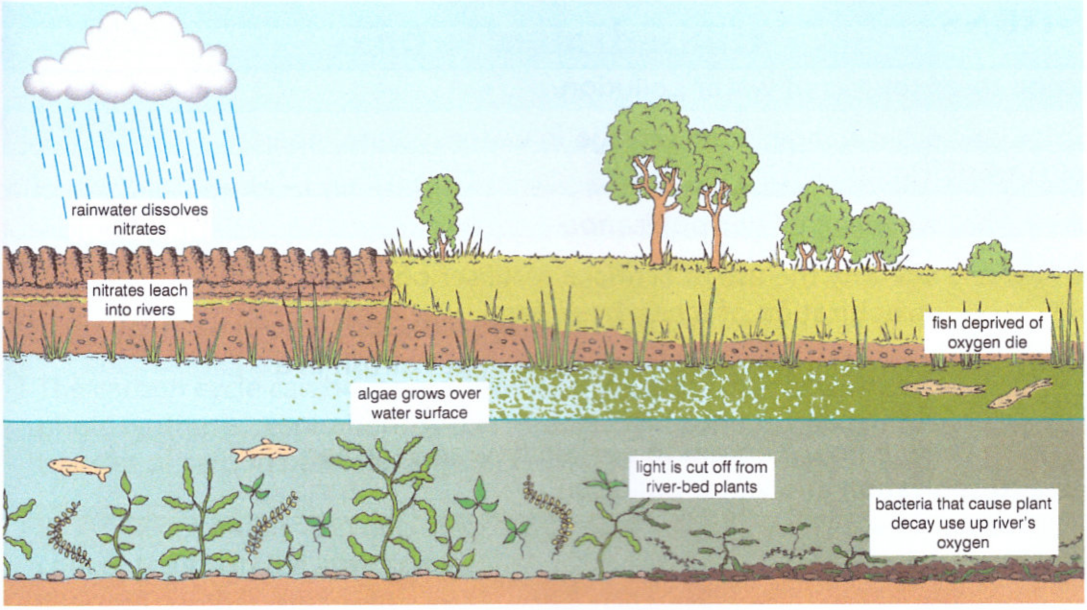
Fertilisers are chemicals that farmers use on fields to add nutrients, such as nitrates, that help the crops to grow better and so produce greater yields. However, if a farmer adds more fertiliser to a field than the crop plants can absorb, the remaining nutrients will soak away in ground water into nearby streams and rivers. Also, if there is heavy rainfall soon after the fertiliser has been spread on a field, the nutrients will dissolve in the rainwater and run off the surface of the field into streams and rivers.

The adding of nutrients to water in this way is called **eutrophication**. The nutrients in the water will have the same effect on plants and algae in the water as they have on plants that grow on land, and will encourage them to grow faster. As they grow faster, they respire more rapidly, taking oxygen from the water. This leaves less oxygen in the water for other organisms, such as fish, and those organisms may die.

EXTENDED

The effects of eutrophication on an aquatic ecosystem can be explained in the following way.

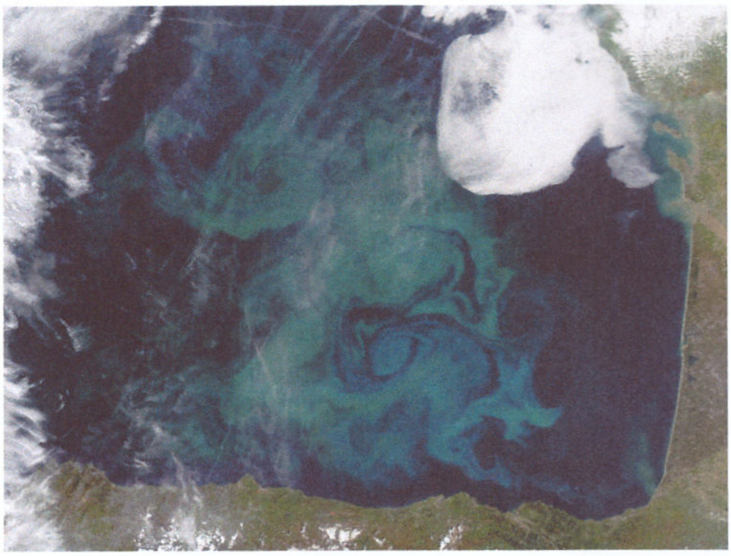
- Eutrophication increases the rate of growth of photosynthesising organisms (producers) in the water, in particular algae and plants that grow at the surface of the water.
- If the plants and algae at the surface grow so much that they block light to plants that grow deeper in the water, the deep-water plants will die because they cannot photosynthesise.
- This will provide more food for decomposers, such as bacteria, which will increase in numbers rapidly.
- The bacteria respire more rapidly in order to make new materials for growth and reproduction. Respiration takes dissolved oxygen from the water, reducing the oxygen concentration of the water.
- Other aquatic (water-living) organisms find it increasingly difficult to get the oxygen they need from the water for respiration.
- If the amount of oxygen dissolved in the water falls too low, many organisms, particularly active animals such as fish, will die.
- The decay of dead organisms in the water provides more nutrients, so more bacteria grow, respire and take more oxygen from the water.
- Eventually, most of the large aquatic plants and animals in the water may die.


rainwater dissolves nitrates
nitrates leach into rivers
algae grows over water surface
fish deprived of oxygen die
light is cut off from river-bed plants
bacteria that cause plant decay use up river's oxygen

Δ Fig. 13.9 Eutrophication can lead to the death of water organisms.

REMEMBER

Eutrophication is often wrongly defined as the pollution of water and death of aquatic organisms. This is incorrect – eutrophication is simply the adding of nutrients. It comes from the Greek word *eutrophia,* meaning 'healthy or adequate nutrition'. Adding nutrients that the ecosystem can use normally may be an advantage, but adding them in excess may lead to the death of aquatic organisms as a result of the depletion of dissolved oxygen in the water. So excess nutrients can cause pollution.



Δ Fig. 13.10 Large-scale algal growth can be seen in satellite photos. This algal bloom occurred in the Baltic Sea in 2010 as a result of fertilisers being washed off the surrounding land.

END OF EXTENDED

QUESTIONS

1. Describe *three* sources of water pollution.
2. Describe one other danger from sewage in water systems, apart from eutrophication.
3. Explain what we mean by *eutrophication*.
4. Give two reasons why the use of artificial fertiliser on a field could cause eutrophication of a nearby stream.
5. Describe how eutrophication can lead to the death of fish in a stream.
6. **EXTENDED** Draw a flow diagram to explain how sewage can cause eutrophication and water pollution.

End of topic checklist

Key words

carbon cycle, combustion, deforestation, fossil fuel, eutrophication, leaching, non-biodegradable, pollution, sewage, soil erosion

During your study of this topic you should have learned:

○ The carbon cycle can be represented as a diagram that shows how photosynthesis, respiration, decomposition and combustion contribute to the transfer of carbon between organisms and the environment.

○ **EXTENDED** Combustion and deforestation can rapidly increase the carbon dioxide concentration in the atmosphere.

○ Deforestation can damage the environment by causing species to become extinct, increasing loss of soil and the risk of flooding, and by resulting in more carbon dioxide in the atmosphere.

○ Why deforestation has undesirable effects on the environment.

○ Pollution of water may be caused by discarded rubbish, chemical waste, untreated sewage and fertilisers.

○ **EXTENDED** Eutrophication, caused by the addition of nutrients to water sources, increases the rate of growth of surface plants and algae that block light to plants lower in the water. Lower plants die and are decayed by bacteria that remove oxygen from the water for respiration. This leaves little oxygen in the water for other organisms such as fish.

○ Plastics that are non-biodegradable may damage aquatic ecosystems because they do not decay.

End of topic questions

Note: The marks given for these questions indicate the level of detail required in the answers. In the examination, the number of marks given to questions like these may be different.

1. **EXTENDED** If rainforest is cleared on a large scale and then left to recover, it is rare that the same species of plants and animals return to the area, even after many years. Explain why this happens, referring to soil fertility, climate and biodiversity in your answer. **(4 marks)**

2. Rivers and lake that are used for water supplies may be monitored to make sure that the water in them is safe for use. One way of monitoring is to measure the amount of oxygen that is used by the water (the oxygen demand) over a period of 5 days.

   a) Why might concentration of oxygen decrease in the water? Explain your answer. **(2 marks)**

   b) In this test would polluted water use more oxygen than unpolluted water? Explain your answer. **(2 marks)**

   Another way of monitoring the water is to sample the small organisms that live in it. Some species, such as worms, are better adapted for living in water that has a low oxygen concentration. Other species, such as mayfly larvae, need a high concentration of oxygen in the water.

   c) Which of the two species above would be more common in polluted water? Explain your answer. **(2 marks)**

   d) What does *adapted* mean? **(1 mark)**

   e) Why might sampling the organisms be a better measure of the long-term health of the water than measuring the oxygen demand of the water? **(2 marks)**

3. In parts of Europe, farmers now use satellite technology to help them see which parts of a field need additional fertiliser, and how much fertiliser they need.

   a) Why do farmers add fertiliser to their fields? **(1 mark)**

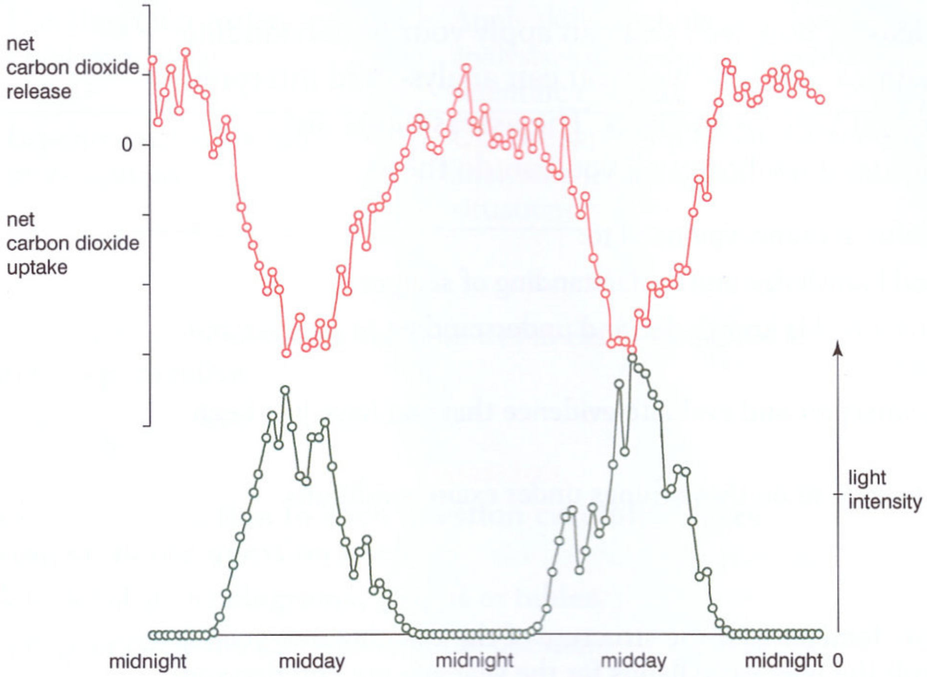
   b) What might happen if a farmer adds too much fertiliser to a field? **(1 mark)**

   c) Explain as fully as you can how this could result in water pollution. **(4 marks)**

   d) Is this referring to the use of satellite imaging technology, or the use of fertilisers as a technology to improve crop growth/yield? **(2 marks)**

End of topic questions continued

4. The graph in Fig.13.11 shows the change in carbon dioxide concentration above a forest over 2 days, and the light intensity just above the top of the trees.



Δ Fig. 13.11 Changes in light intensity and carbon dioxide concentration above a forest.

a) Explain the changes in light intensity shown in the graph. **(2 marks)**

b) Explain the changes in carbon dioxide concentration shown in the graph. (Remember there are more organisms than just the trees in the forest.) **(4 marks)**

Doing well in examinations

INTRODUCTION

Examinations will test how good your understanding of scientific ideas is, how well you can apply your understanding to new situations and how well you can analyse and interpret information you have been given. The assessments are opportunities to show how well you can do these.

To be successful in exams you need to:

- ✓ have a good knowledge and understanding of science
- ✓ be able to apply this knowledge and understanding to familiar and new situations
- ✓ be able to interpret and evaluate evidence that you have just been given.

You need to be able to do these things under exam conditions.

OVERVIEW

Ensure you are familiar with the structure of the examinations you are taking. Consult the relevant syllabus for the year you are entering your examinations for details of the different papers and the weighting of each, including the papers to test practical skills. Your teacher will advise you of which papers you will be taking.

You will be required to perform calculations, draw graphs and describe, explain and interpret biological ideas and information. In some of the questions the content may be unfamiliar to you; these questions are designed to assess data-handling skills and the ability to apply biological principles and ideas in unfamiliar situations.

ASSESSMENT OBJECTIVES AND WEIGHTINGS

For the Cambridge IGCSE Co-ordinated Sciences examination, the assessment objectives and weightings are as follows:

- ✓ A01: Knowledge with understanding (50%)
- ✓ A02: Handling information and problem solving (30%)
- ✓ A03: Experimental skills and investigations (20%).

The types of questions in your assessment fit the three assessment objectives shown in the table.

Assessment objective	Your answer should show that you can…
A01 Knowledge with understanding	Recall, select and communicate your knowledge and understanding of science.
A02 Handling information and problem solving	Apply skills, including evaluation and analysis, knowledge and understanding of scientific contexts.
A03 Experimental skills and investigations	Use the skills of planning, observation, analysis and evaluation in practical situations.

EXAMINATION TECHNIQUES

To help you to work to the best of your abilities in exams, there are a few simple steps to follow.

Check your understanding of the question.

- ✓ **Read the introduction to each question carefully before moving on to the question itself**.
- ✓ Look in detail at any **diagrams, graphs** or **tables**.
- ✓ Underline or circle the **key words** in the question.
- ✓ **Make sure you answer the question that is being asked** rather than the one you wish had been asked!
- ✓ Make sure you understand the meaning of the '**command words**' in the questions.

REMEMBER

Remember that any information you are given is there to help you to answer the question.

EXAMPLE

- ✓ **'Give'**, **'state'**, **'name'** are used when recall of knowledge is required, for example you could be asked to give a definition or provide the best answers from a list of options.
- ✓ **'Describe'** is used when you have to give the main feature(s) of, for example, a biological process or structure.
- ✓ **'Explain'** is used when you have to give reasons, e.g. for some experimental results or a biological fact or observation. You will often be asked to 'explain your answer', i.e. give reasons for it.

- ✓ **'Suggest'** is used when you have to come up with an idea to explain the information you're given – there may be more than one possible answer, no definitive answer from the information given, or it may be that you will not have learned the answer but have to use the knowledge you do have to come up with a sensible one.
- ✓ **'Calculate'** means that you have to work out an answer in figures.
- ✓ **'Plot'** and **'draw a graph'** are used when you have to use the data provided to produce graphs and charts.

Check the number of marks for each question

- ✓ Look at the **number of marks** allocated to each question.
- ✓ Look at the **space provided** to guide you as to the length of your answer.
- ✓ Make sure you include at least as many points in your answer as there are marks.
- ✓ Write neatly and keep within the space provided.

REMEMBER

Beware of continually writing too much because it probably means you are not really answering the questions. Do not repeat the question in your answer.

Use your time effectively

- ✓ Don't spend so long on some questions that you don't have time to finish the paper.
- ✓ Check how much time you have left regularly.
- ✓ If you are really stuck on a question, leave it, finish the rest of the paper and come back to it at the end.
- ✓ Even if you eventually have to guess at an answer, you stand a better chance of gaining some marks than if you leave it blank.

ANSWERING QUESTIONS

Multiple choice questions

- ✓ Select your answer by placing a cross (not a tick) in the box. In the final exam, you will select multiple-choice answers on a separate answer sheet using a pencil.

Short answer and structured questions

- ✓ In short-answer questions, **don't write more than you are asked for**.
- ✓ You may not gain any marks, even if the first part of your answer is correct, if you've written down something incorrect later on or which contradicts what you've said earlier. This may give the impression that you haven't really understood the question or are guessing.
- ✓ Always use **clear scientific language**. In some short-answer questions one or two words may be sufficient, but in longer questions you should aim to use full sentences.
- ✓ Present the information in a logical sequence.
- ✓ Don't be afraid to also use **labelled diagrams** or **flow charts** if it helps you to show your answer more clearly.

Questions with calculations

- ✓ **In calculations always show your working**.
- ✓ Even if your final answer is incorrect, you may still gain some marks if part of your attempt is correct.
- ✓ If you just write down the final answer and it is incorrect, you will get no marks at all.
- ✓ Write down your answers to as many **significant figures** as are used in the numbers in the question (and no more). If the question doesn't state how many significant figures then a good rule to follow is to quote three significant figures.
- ✓ Don't round off too early in calculations with many steps.
- ✓ You may also lose marks if you don't use the correct **units**. In some questions the units will be mentioned, e.g. calculate the mass in grams; or the units may also be given on the answer line. If the numbers you are working with are very large, you may need to make a conversion, e.g. convert joules into kilojoules or millimetres into metres.

Finishing your exam

- ✓ When you've finished your exam, **check through** your paper to make sure you've answered all the questions.
- ✓ Check that you haven't missed any questions at the end of the paper, or turned over two pages at once and missed questions.
- ✓ Cover over your answers and read through the questions again. Then check that your answers are as good as you can make them.

REMEMBER

You will be asked questions on investigative work. It is important that you understand the methods used by scientists when carrying out investigative work.

More information on carrying out practical work and developing your investigative skills are given in the next section.

Exam-style questions

All exam-style questions and sample answers in this title were written by the author(s). In examinations marks may be given differently.

Question 1

This question is about the characteristics of living things.

a) Copy and complete the sentences by writing the most appropriate word in each space.

Use only words from the box.

detect	development	energy	gravity
growth	light	location	nutrition
position	respiration	respond	sensitivity

.... is the taking in of substances needed for energy and for .... and ....

.... is a series of reactions that take place in living cells to release .... from nutrient molecules so that cells can use this to keep them alive.

.... is the ability to .... and .... to changes in external and internal conditions.

Movement causes a change in .... of the organism. In animals, this involves their entire bodies. Plants often move parts of their body in response to external stimuli, such as .... and .... **(12)**

b) Define the term *excretion*. **(3)**

c) Which of the characteristics shown by living things are shown by a motor car? **(4)**

(Total 19 marks)

Question 2

Most living organisms are made up of cells.

Copy and complete the sentences by writing the most appropriate word in each space.

The .... holds the cell together and controls substances entering and leaving the cell. The .... is the jelly-like substance contained within the cell. It is where many different chemical processes occur.

The .... is the control centre of the cell and contains genetic material as .... These control how a cell grows and works.

Exam-style questions continued

Plant cells also have features that are not found in animal cells. These include the ...., made of ...., which gives the cell extra support and defines its shape.

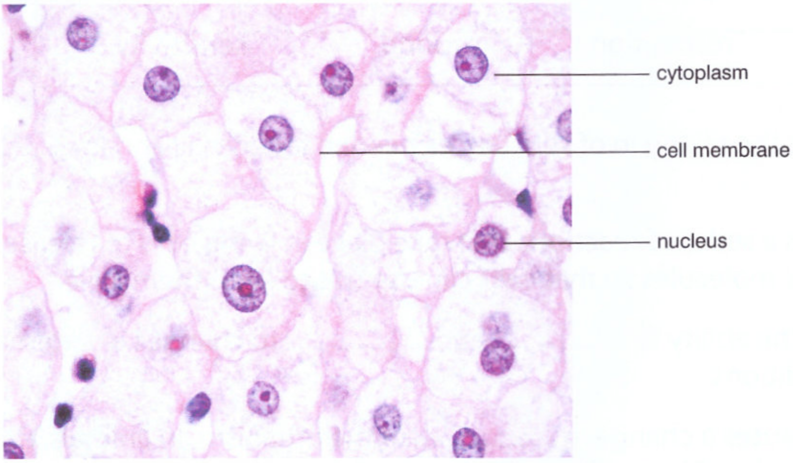
Many plant cells have a large central, permanent .... that contains cell sap. It is used for storage of some chemicals, and to support the shape of the cell.

Plant cells exposed to the light contain .... These contain the green pigment ...., which absorbs the light energy that plants use for the process of .... **(10)**

(Total 10 marks)

Question 3

The light micrograph shows a cell from the liver of a human.



a) State the functions of the three structures highlighted above. **(6)**

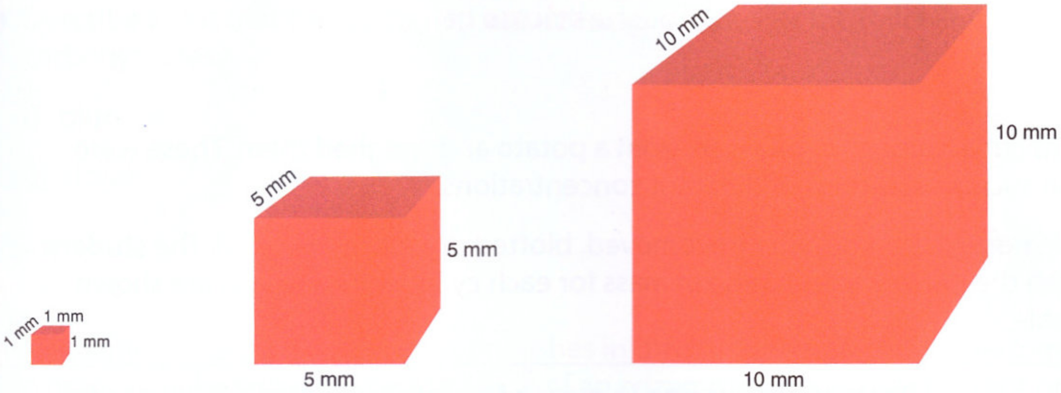
b) How many liver cells, laid side-to side, would there be in a piece of liver tissue 1 cm across? Show your working. **(2)**

(Total 8 marks)

EXTENDED Question 4

A Biology student set up an investigation in which three cubes of different sizes were cut from an agar jelly block. The agar jelly contained a red indicator that turns blue in the presence of alkali.

The cubes were placed in an alkali. The student measured the time taken for the cubes to turn completely blue.



a) What is the name of the process that causes the alkali to penetrate the agar jelly? **(1)**

b) EXTENDED The student used cubes of three dimensions:

Dimensions of cube, mm
1 × 1 × 1
5 × 5 × 5
10 × 10 × 10

For each cube, calculate its:

i) surface area

ii) volume

iii) surface area : volume ratio. **(9)**

Dimensions of cube/mm	**i) Surface area of cube/mm^2**	**ii) Volume of cube/mm^3**	**iii) Surface area : volume ratio**
1 × 1 × 1			
5 × 5 × 5			
10 × 10 × 10			

c) EXTENDED Explain the relationship between surface area and volume as the cube increases in size. **(1)**

d) EXTENDED During the biology lesson, the alkali penetrated the two smaller cubes, but by the end of the lesson, the 10 mm × 10 mm × 10 mm cube had still not turned completely blue.

i) Explain these results. **(3)**

ii) Explain what implications this has for organisms of increasing size. **(3)**

(Total 17 marks)

Exam-style questions continued

Question 5

A student cut a number of cylinders from a potato and weighed them. These were placed in sucrose solutions of different concentrations.

After one hour, the cylinders were removed, blotted dry and reweighed. The student calculated the percentage change in mass for each cylinder. The results are shown in the table.

Concentration of sucrose/g per cm^3	**Percentage change in mass of potato cylinders**				**Average percentage change in mass**
	Experiment 1	**Experiment 2**	**Experiment 3**	**Experiment 4**	
0.0	+31.4	+33.7	+31.2	+32.5	
0.2	+20.9	+22.2	+22.8	+21.3	
0.4	−2.7	−1.8	−1.9	−2.4	
0.6	−13.9	−12.8	−13.7	−13.6	
0.8	−20.2	−19.7	−19.3	−20.4	
1.0	−19.9	−20.3	−21.1	−20.3	

a) Calculate the average percentage changes in mass for each of the sucrose concentrations. **(6)**

b) i) Draw a graph of these results. Join the points with a line of best fit. **(4)**

ii) At what concentration of sucrose was there no net movement of water? **(2)**

iii) Describe the changes in mass over the range of sucrose concentrations. **(3)**

iv) State the process involved in these changes in the potato cylinders. **(1)**

(Total 16 marks)

Question 6

The table below lists some molecules that are important biologically.

a) Give the units that each one of the following biological molecules is made up of.

Biological molecule	**Units that make up the molecule**	
Glycogen		**(1)**
Fats		**(2)**
Proteins		**(1)**
Starch		**(1)**

b) Describe a test that can be carried out in the laboratory for the following carbohydrates:

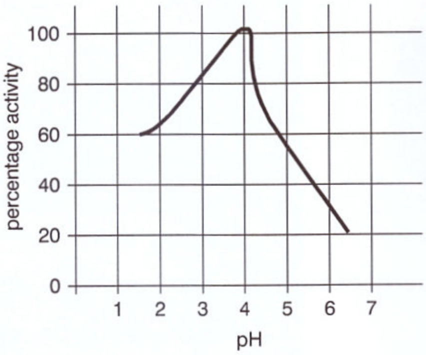
i) glucose **(5)**

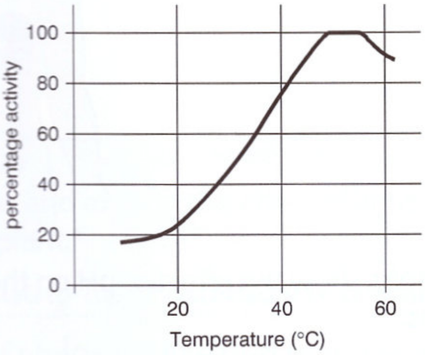
ii) starch. **(4)**

(Total 14 marks)

EXTENDED Question 7

A company that produces enzymes publishes information sheets of their performance. The graphs below show the performance of an enzyme, pectinase, at different pHs and temperatures.



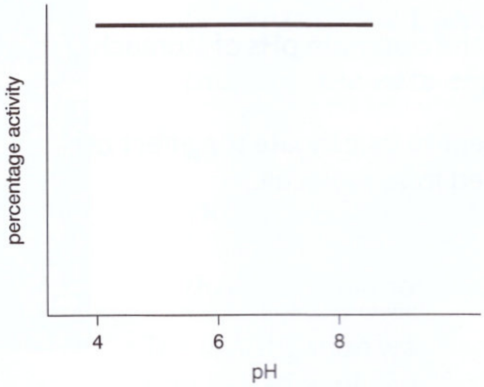


a) Describe and explain the effect of:

i) pH **(6)**

ii) temperature, on the activity of the enzyme pectinase. **(5)**

b) A student finds an information sheet on the effect of pH on the activity of a protease called papain, from the papaya plant.



i) EXTENDED State two proteases produced by the human gut. **(2)**

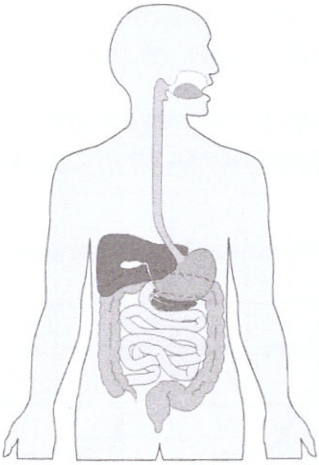
ii) A student says that the graph shows that papain is unaffected by pH. Is the student correct? Explain your answer. **(2)**

(Total 15 marks)

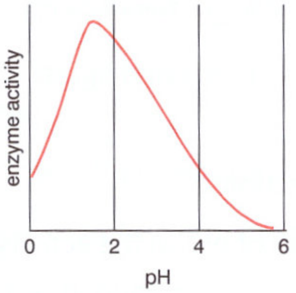
Exam-style questions continued

EXTENDED Question 8

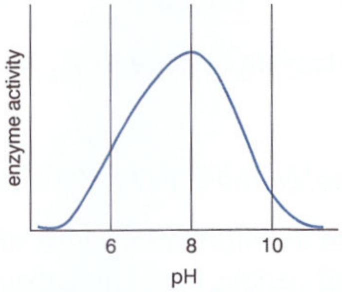
a) In humans, proteases are produced by the stomach, pancreas and small intestine. Copy the diagram and show the location of these organs. **(3)**



b) The graphs show the effect of pH on the activity of two proteases that break down proteins.



stomach protease



small intestine protease

i) EXTENDED What are the optimum pHs of stomach and small intestine proteases? **(2)**

ii) Describe an experiment to investigate the effect of temperature on the breakdown of a named food molecule. **(5)**

(Total 10 marks)

TEACHER'S COMMENTS

a) i) Correct. As light intensity increases, the rate of photosynthesis increases, because light energy supplies energy for the process of photosynthesis. At a certain point, the graph levels off, so any further increase in light intensity after that point will result in no further increase in photosynthesis. At this point, some other factor must be limiting, for example carbon dioxide, and preventing any further increase.

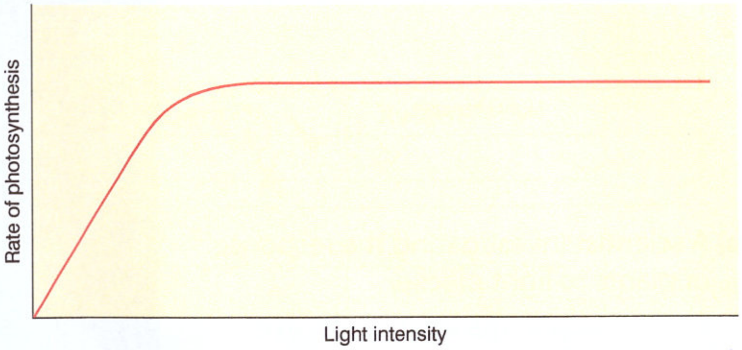
ii) One mark has been given for the correct graph. The student has not responded to the second part of the question – 'Explain the shape of the graph you have drawn'. To gain a second mark, the student needed to explain that, as carbon dioxide was a factor that was limiting the rate of photosynthesis where the graph levels off, in a higher concentration of carbon dioxide the graph will continue to a higher point (i.e. a higher rate of photosynthesis) until it

Sample student answers

EXTENDED Question 9

Plants respond to the light available.

a) The graph below shows the effect of light intensity on photosynthesis in a single-celled plant.



i) Describe and explain the effect of light intensity on the plant. **(4)**

Increasing light intensity increases the rate of photosynthesis up to a certain point. ✓ ①

This is because light energy is needed for photosynthesis. ✓ ①

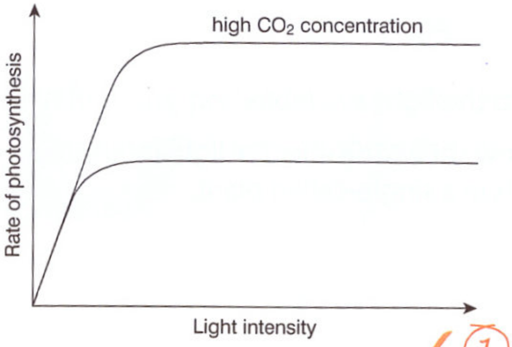
The graph stops getting steeper because increasing the light intensity can't increase the rate of photosynthesis any more. ✓ ①

This is because another factor is limiting the rate of photosynthesis. ✓ ①

The investigation was also repeated in a high concentration of carbon dioxide.

ii) Sketch a graph of what you would expect so you can compare it with the graph above. Explain the shape of the graph you have drawn. **(3)**

Sample student answers continued



✓ ①

✗

b) A scientist investigating the response of plants to light placed:

- one group in the light, given even illumination
- one group of plants in the dark, and
- one group exposed to light from one side.

The plants were in an atmosphere of radioactive carbon dioxide, and after five hours, the amount of radioactive auxin in the area below the shoot tip was measured. The scientist's results are shown below.

	Plants in the light	Plants in the dark	Plants exposed to light from one side	
			Dark side	Lighted side
Total radioactive auxin/ counts per minute	2985	3004	2173	878

Explain fully what these results show about the effect of light on auxin in the plants. (4)

There is not much difference between the amount of auxin in the plants in the dark, the plants in the light or the plant that was half in the light and half in the dark. ✓ ①

This shows that altering the levels of light does not make any difference to the production of auxin. ✓ ①

(Total 11 marks

7/11

again levels off. The third mark would have been given for stating that at this point, with light and carbon dioxide being available, another factor (e.g. temperature) must be preventing any further increase in the rate of photosynthesis.

b) The student has correctly identified that there is no significant difference between the amount of auxin in the plants in the light, the dark or those illuminated on one side. A further mark is gained by correctly stating that this shows that light has no effect on the production of auxin.

To gain further marks, the student needed to provide a more in-depth explanation using the results, such as 'This shows that light has no effect on the production of auxin. In the plant illuminated from one side, about 71% of the auxin in the plant is on the dark side, so as the total auxin was unaffected by light, the auxin must have been redistributed from the light to dark side.'

EXTENDED Question 10

The leaf is the main organ of photosynthesis.

a) Write a word and symbol equation for photosynthesis. **(5)**

b) EXTENDED Explain how the leaf is adapted to exchanging gases required for photosynthesis. **(5)**

c) Chemical substances in a plant are transported in the xylem and phloem.

Copy and complete the table below.

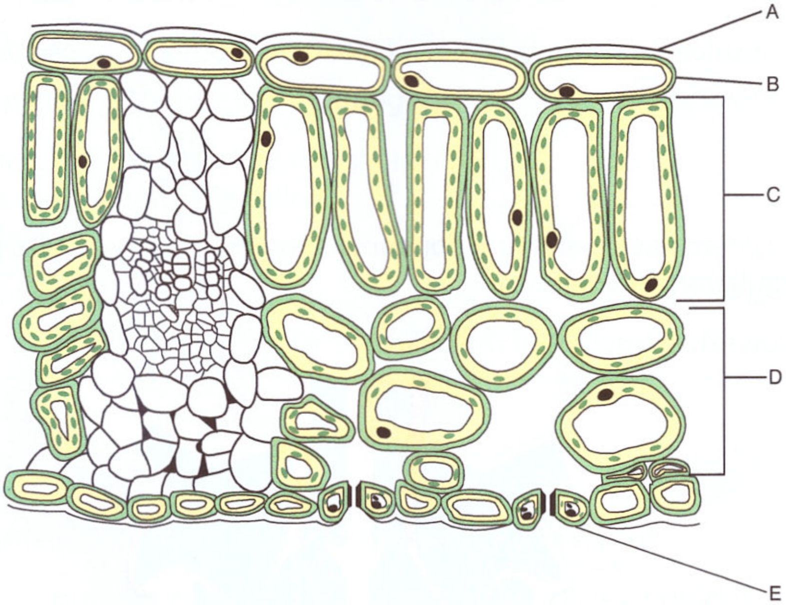
	Phloem	**Xylem**
Substances transported	(2)	(2)
Substances are transported: **from**	(1)	(1)
to	(1)	(1)

(8)

(Total 18 marks)

Question 11

The diagram shows a section through a leaf.



a) Name parts A–E shown in the diagram. **(5)**

b) The leaf is the main organ of photosynthesis. Write a word equation for photosynthesis. **(3)**

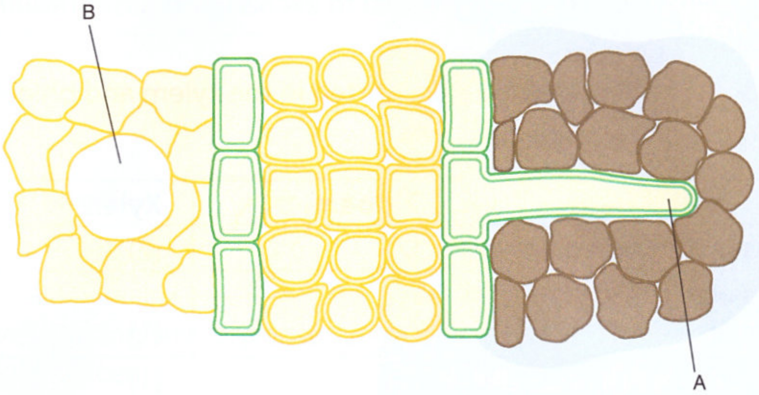
c) Define the term *transpiration*. **(3)**

d) Describe a technique used to investigate the effect of temperature on transpiration rate. **(7)**

(Total 18 marks)

EXTENDED Question 11

a) The diagram below shows a section of a plant root surrounded by soil particles.



i) Identify the parts of the plant root, A and B. **(2)**

ii) EXTENDED Explain the importance of water potential in the uptake and transport of water by plant roots. **(7)**

b) The effect of osmosis on animal cells is different from its effect on plant cells.

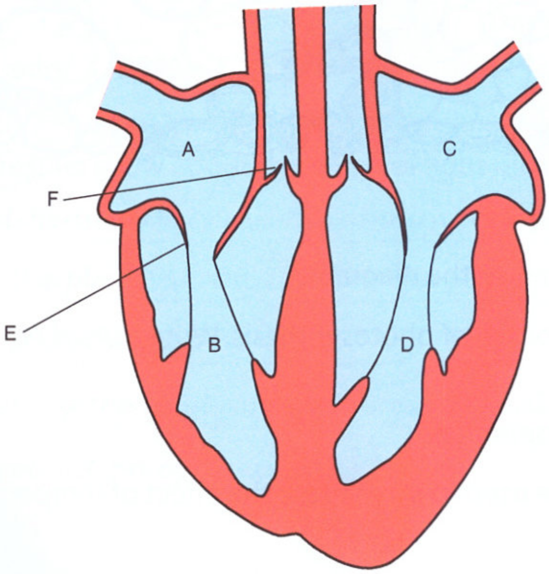
i) EXTENDED Explain how osmosis is involved in the body's response to a cholera infection. **(5)**

(Total 15 marks)

Question 12

The circulatory system has several functions, including the transport of substances, temperature regulation and defence.

The diagram shows the structure of the heart.



a) Name the chambers of the heart, A, B, C and D. **(4)**

b) Copy and complete the table for each of the different components of the blood.

Component of blood	Function
Red blood cells	
White blood cells	
Platelets	
Plasma	

(8)

(Total 12 marks)

Question 13

a) Yeast, a fungus, is used in the production of biofuel.

i) Give the word equation for the production of ethanol by yeast. **(2)**

ii) Describe how yeast cells are involved in the process. **(1)**

b) Compare the energy produced by yeast undergoing anaerobic respiration with yeast undergoing aerobic respiration. **(1)**

(Total 4 marks)

Question 14

This question is about plants' responses towards stimuli.

Copy and complete the sentences by writing the most appropriate word in each space.

Growth in response to the direction of light is called ....
If the growth is toward light, it is called .... ,
as shown by plant ....

Growth in response to gravity is called .... Plant roots are .... This response helps the plant .... to grow .... , so the plant can obtain the .... it needs. **(Total 8 marks)**

Question 15

The nervous system is involved in the body's response to stimuli.

a) When a person puts her hand on a hot object, she removes it quickly using a reflex action.

i) Draw a diagram to show the reflex arc involved. **(6)**

ii) Shortly after she removes her hand, she realises that she has touched a hot object. Explain how this occurs. **(3)**

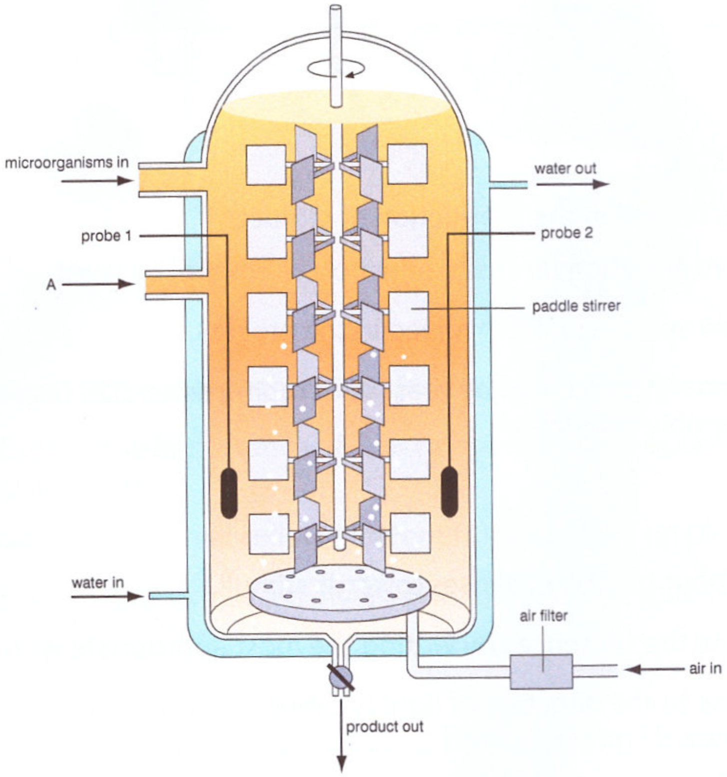
b) **EXTENDED** What is the name of the other system involved in the body's coordination? How does the response of this system differ from the nervous system? **(4)**

(Total 13 marks)

Exam-style questions continued

EXTENDED Question 16

The diagram shows the structure of an industrial fermenter used to culture a microorganism that produces a medicinal drug.


microorganisms in
probe 1
A
water in
water out
probe 2
paddle stirrer
air filter
air in
product out

a) State why many drugs are produced with microorganisms rather than manufactured from chemical raw materials. **(2)**

b) i) Suggest what may be pumped into the fermenter at point A. **(1)**

ii) Suggest two factors that probes 1 and 2 may be designed to measure. **(2)**

c) In the fermenter, explain fully the use of:

i) the paddle stirrer **(2)**

ii) water circulating around the fermenter. **(3)**

d) Give one way in which the manufacturer ensures that this microorganism grows rather than others. **(1)**

e) What type of respiration is the microorganism carrying out in the fermenter? Explain your answer. **(2)**

(Total 13 marks)

Question 17

a) The passage below describes the process of sexual reproduction.

Use suitable words to complete the sentences in the passage.

Sexual reproduction is the most common method of reproduction for the majority of larger organisms, including almost all animals and plants. To produce a new organism, two   fuse. This process is known as   . (2)

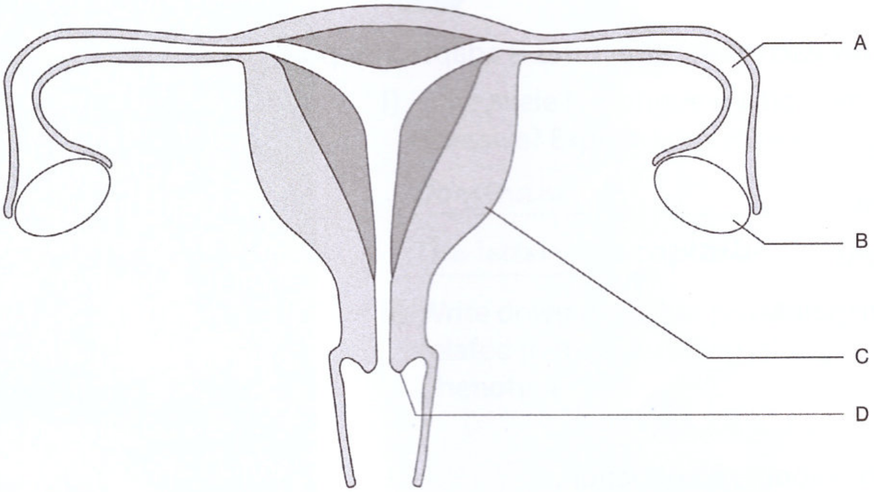
Usually, sexual reproduction involves   parent organisms of the same species. The   formed is genetically different from each of the parents. (2)

b) **EXTENDED** Give one advantage and one disadvantage of:

i) asexual reproduction. (2)

ii) sexual reproduction. (2)

c) **i)** Label the diagram of the human female reproductive system. (6)



ii) Draw a flow chart to illustrate the processes involved in labour and birth. (6)

d) State **one** method of each type of birth control:

i) chemical (1)

ii) barrier (1)

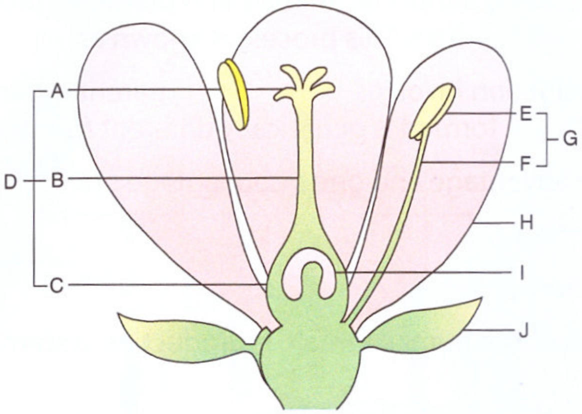
iii) surgical. (1)

(Total 23 marks)

Question 18

Flowers are adapted to be pollinated by insects or by the wind.

a) Name the structures of an insect-pollinated flower shown in the diagram below. **(10)**



b) Explain how each of the structures is adapted for pollination in wind-pollinated flowers:

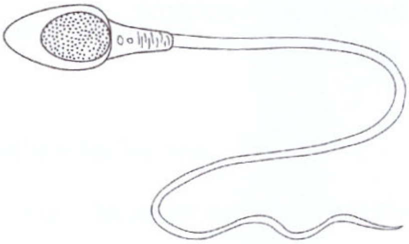
- **i)** petals **(2)**
- **ii)** stigma **(2)**
- **iii)** stamens **(2)**
- **iv)** pollen grains. **(2)**

(Total 18 marks)

EXTENDED Question 19

This question is about reproduction.

a) The diagram shows a human sperm.



Explain how the sperm is adapted to fertilising a human egg. **(4)**

b) Explain the roles of hormones in controlling the menstrual cycle and preparing the uterus for a fertilised egg. **(3)**

c) Discuss the advantages of breast-feeding compared with bottle-feeding. **(3)**

(Total 10 marks)

TEACHER'S COMMENTS

a) i) Correct – dominant.

The rest of the answer is too vague. It should be more specific, such as 'The two letters making up the genotype are written in upper case.'

ii) Correct.

b) i) The answer is correct, but could be better worded. Rather than saying 'the couple', it is better to say that the man could be TT or Tt, and the woman could be TT or Tt.

ii) Both statements are correct, but only two marking points have been addressed. The student is correct, that unless both parents were Tt, all children would be tongue rollers, but the answer would benefit from two statements of explanation.

c) First of all, it should be made clear that as both the man and woman can roll their tongue, they must have at least one T allele each.

d) There should then be a sentence of explanation to link the statements, such as:

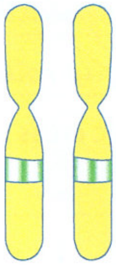
'Without the presence of a t allele in both parents, all the children would be tongue rollers.'

Sample student answers

Question 20

People are either able to roll their tongue into a U-shape, or unable to roll their tongue. Tongue rolling is controlled by a single pair of genes which has two alleles.

a) The diagram shows a pair of chromosomes:



Genotype TT:
can roll tongue

i) Is the allele for tongue rolling dominant or recessive? Explain your answer. **(2)**

Dominant ✓ ①

The letters are capitals. ✗

ii) Write down the other possible genotypes related to tongue rolling, along with their phenotypes. **(2)**

Tt - The phenotype is a tongue roller. ✓ ①

tt - The phenotype is non-tongue roller (cannot roll tongue). ✓ ①

b) A couple who can both roll their tongues have children.

i) Give the possible genotypes of the man and the woman. **(2)**

The couple could be TT ✓ ①

or Tt. ✓ ①

Sample student answers continued

ii) Their first child cannot roll his tongue; the second one can.

What does this tell you about the genotypes of the couple? Explain your answer fully. **(4)**

The genotype of both the man and women must be Tt. ✓ ①

Because otherwise all the children would be tongue rollers. ✓ ①

iii) Show the genetic cross involved. **(4)**

Tt x Tt ✓ ①

↓

TT Tt tT tt ✓ ①

(Total 14 marks)

9/14

iii) The diagram illustrates the cross correctly, but lacks detail.

The best way of illustrating the cross is to use a Punnett square, showing each stage of the cross:

the genotypes of the parents

the different alleles that could be passed on to the offspring from the mother and father (the alleles in the egg cells and sperm cells)

the possible combinations of alleles in the offspring (genotypes)

the possible phenotypes produced.

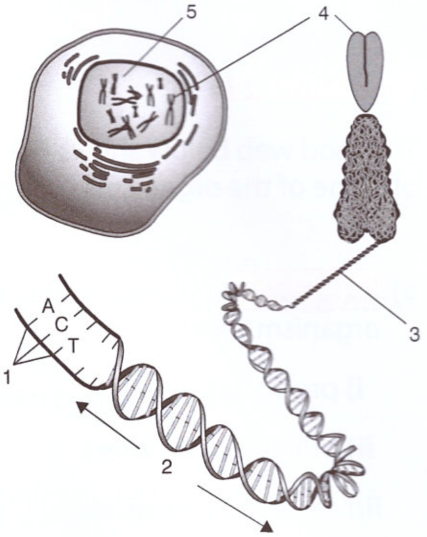
		Mother possible alleles in eggs	
		T	t
Father possible alleles in sperm	T	TT Tongue roller	Tt Tongue roller
	t	Tt Tongue roller	tt Non-tongue roller

A further point is the way in which the student has written the third possible genotype in their answer (tT). Although not incorrect, the convention is to write the dominant allele first, so it should be written Tt.

Question 21

The diagram shows a cell and some of the structures in it.

Identify the structures 1, 2, 3, 4 and 5.



(Total 5 marks)

Question 22

A horse has a chromosome number of 64.

a) State whether each statement refers to mitosis, meiosis, both or neither. **(6)**

- **i)** The chromosome number in each daughter cell is 64.
- **ii)** The daughter cells are haploid.
- **iii)** Two identical cells are produced.
- **iv)** The nuclear membrane breaks, disappears at the beginning, and is reformed at the end of the process.
- **v)** Some variability occurs in the alleles of parent and daughter chromosomes.
- **vi)** Occurs when new red blood cells are produced in the blood of the horse.

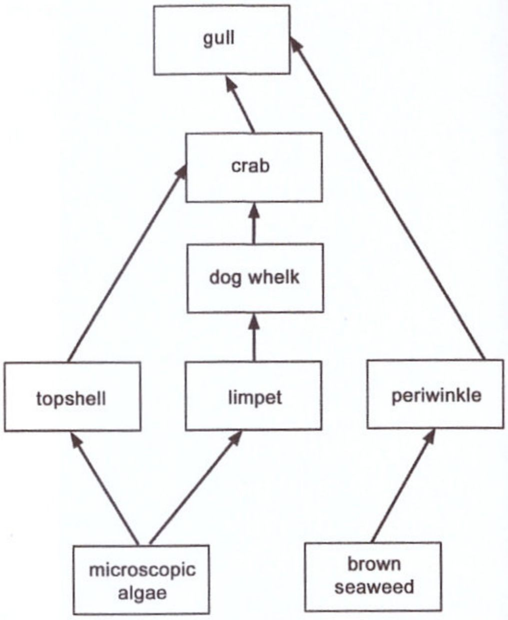
b) Explain why a horse's gametes are produced by meiosis. **(5)**

(Total 11 marks)

Exam-style questions continued

Question 23

The food web below shows the relationship of some of the organisms on a rocky shore.



a) EXTENDED In the food web, state which organisms are:

- **i)** producers (2)
- **ii)** primary consumers (3)
- **iii)** secondary consumers. (3)

b) In an ecosystem, the numbers of crabs is severely reduced.

- **i)** State **one** reason for the reduction of an organism in an ecosystem. (3)
- **ii)** Describe the impact on dog whelks, limpets and gulls in the food web. (5)

c) A student investigated the distribution of a species of brown seaweed and periwinkles down a rocky shore. Her results are shown here.

Distance below high water on seashore/ metres	**Distribution of organisms**	
	Observed distribution of brown seaweed	**Density of periwinkles/ mean number of periwinkles per m²**
0	Absent	0
10	Rare	16
20	Occasional	52
30	Abundant	156
40	Abundant	128
50	Occasional	44
60	Rare	12

Suggest two reasons for the distribution of the periwinkles. (2)

(Total 18 marks)

Question 24

Nutrients are cycled in nature.

a) The passage below describes the stages in the carbon cycle.

Use suitable words to complete the sentences in the passage. **(9)**

.... from the atmosphere is converted to complex carbon compounds in .... by the process of .... This is often called carbon ....

Plants are then often eaten by ...., which build up their own complex carbon compounds.

The process of .... in both plants and animals, returns some of this carbon back to the atmosphere as ....

When organisms die, their bodies decay as they are worked on .... by .... Some of the complex carbon compounds are taken into the bodies of these organisms, where some may be converted to carbon dioxide during their ....

b) EXTENDED By what other process does carbon dioxide enter the air? **(1)**

(Total 10 marks)

EXTENDED Question 25

In an ecosystem, the following measurements were made.

Organism	Number in ecosystem	Biomass of organisms/g
Oak trees	1	500 000
Aphids	100 000	100
Ladybirds	200	10

a) Draw a food chain to illustrate the feeding relationships of the three organisms. **(3)**

b) EXTENDED In observations of the ecosystem, ladybirds were seen to be fed on by spiders, and spiders fed on by blackbirds.

i) Draw a food chain to illustrate these feeding relationships. **(1)**

ii) Explain fully why food chains longer than this are rare. **(5)**

(Total 9 marks)

Exam-style questions continued

Question 26

The table gives information on how the land area covered by forest has changed from 1990 to 2005.

Country	**Area covered by forest/millions of hectares**		**Area of forest lost from 1990 to 2005/%**
	1990	**2005**	
Bolivia	109.9	58.7	46.6
Brazil	851.5	477.7	
Colombia	113.9	60.7	
French Guiana	9.0	8.1	
Peru	125.5	68.7	
Suriname	16.3	14.8	
Venezuela	91.2	47.7	

Data from www.mongabay.com

a) **EXTENDED** Calculate the area of forest lost for each country, as a percentage of the area in 1990. The first one has been done for you. **(6)**

b) During the time period 1990 to 2005, in which country is there:

- **i)** the greatest deforestation? **(1)**
- **ii)** the least deforestation? **(1)**

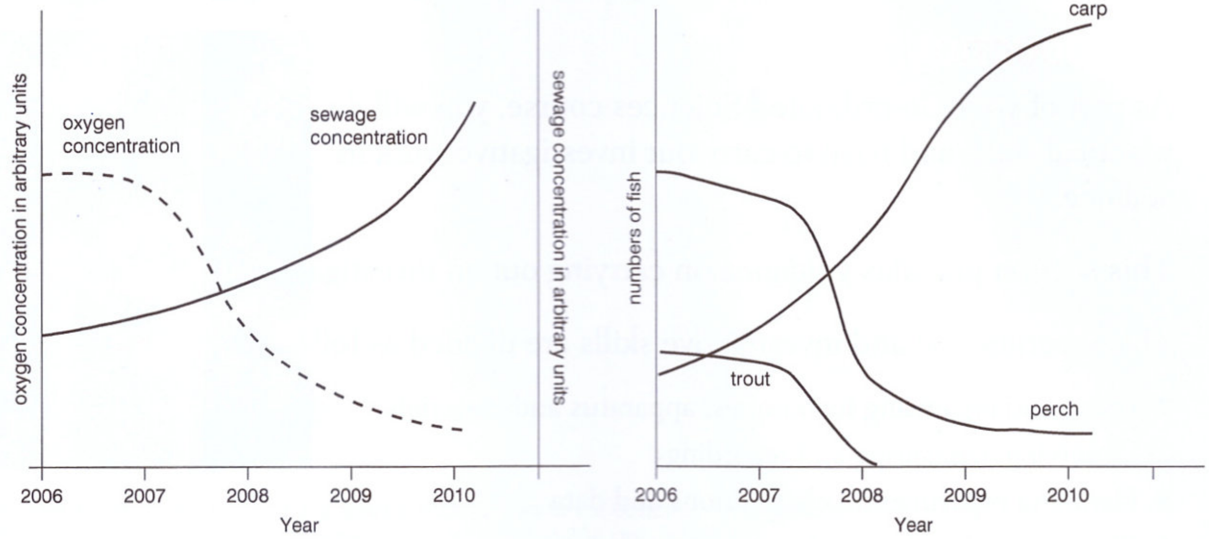
c) Suggest two reasons for deforestation. **(2)**

d) List the effects of deforestation. **(5)**

(Total 15 marks)

EXTENDED Question 27

The effect of sewage into a river was monitored over a number of years. The results are shown in the graphs.



a) i) Describe the trends in sewage and oxygen concentration between 2006 and 2010. **(2)**

ii) Explain why sewage had this effect on the oxygen concentration in the water. **(3)**

b) Describe and explain the effects of the changing oxygen concentration on fish populations. **(6)**

(Total 11 marks)

Developing experimental skills

INTRODUCTION

As part of your Co-ordinated Sciences course, you will develop practical skills and have to carry out investigative work in science.

This section provides guidance on carrying out an investigation.

The experimental and investigative skills are divided as follows:

1. Using and organising techniques, apparatus and materials
2. Observing, measuring and recording
3. Handling experimental observations and data
4. Planning and evaluating investigations.

1. USING AND ORGANISING TECHNIQUES, APPARATUS AND MATERIALS

Learning objective: to demonstrate and describe appropriate experimental and investigative methods, including safe and skilful practical techniques.

Questions to ask:

How shall I use the equipment and chemicals safely to minimise the risks – what are my safety precautions?

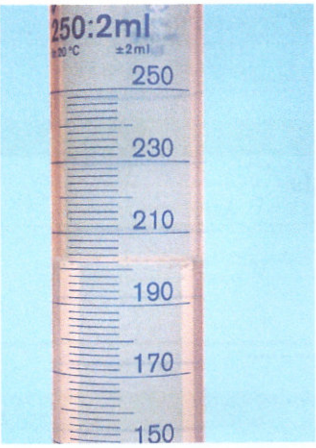
- ✓ When writing a Risk Assessment, investigators need to be careful to check that they've matched the hazard with the concentration of a chemical used. Many acids, for instance, are corrosive in higher concentrations, but are likely to be irritants or of low hazard in the concentration used when working in biology experiments.
- ✓ Don't forget to consider the hazards associated with all the chemicals and biological materials, even if these are very low.
- ✓ You may be asked to justify the precautions taken when carrying out an investigation.

How much detail should I give in my description?

- ✓ You need to give enough detail so that someone else who has not done the experiment would be able to carry it out to reproduce your results.

How should I use the equipment to give me the precision I need?

- ✓ You should know how to read the scales on the measuring equipment you are using.
- ✓ You need to show that you are aware of the precision needed.



Δ Fig 6.1 The volume of liquid in a burette must be read to the bottom of the meniscus. The volume in this measuring cylinder is 202 cm³ (ml), not 204 cm³.

EXAMPLE 1

This is an extract from a student's notebook. It describes how she carried out an experiment to investigate the production of carbon dioxide by yeast at different temperatures.

What are my safety precautions?

a) Chemical

I have looked up the hazards associated with the chemical I am using:

Glucose (solutions from 0.05 to 0.25 M): LOW HAZARD

Although it is only a low hazard, it is still best to wear eye protection when using the solutions, especially as some of the liquids will be hot. It is also important to handle all chemicals carefully, and wipe up any spills of liquid.

COMMENT

The student has used a data source to look up the chemical hazards.

b) Organism

I found my information on yeast from the Fisher Scientific website:

Dried yeast may cause eye, skin, and respiratory tract irritation. It is expected to be a low hazard for usual handling. If the dust is inhaled, you should 'remove from exposure and move to fresh air immediately'.
I will handle the powdered yeast carefully when making up my suspension, trying to avoid making any dust.

COMMENT

The student has used a data source to look up the biological hazards.

c) Equipment

I must be careful when using the water bath not to get water near the electrical sockets.
I need to handle the glassware (conical flask, gas syringe and glass tubing) carefully. In particular, I need to protect my hands with a towel (or glove) when linking together the glass delivery tubes from the rubber bung in the conical flask to the gas syringe with rubber tubing. The tubing needs to be lubricated with water and I need to hold my hands close together to limit the movement of glass if a break occurs.

COMMENT

The student has suggested some sensible precautions.

How much detail should I give in my description?

The student's method is given below:

1. A solution of 0.25 M glucose was made up by dissolving 45.00 g of glucose in water to make a litre of solution.
2. 100 cm^3 of the glucose solution was transferred to each of six conical flasks.
3. The conical flask was transferred to a water bath at 20 °C. It was left for a few minutes to reach the temperature.
4. 1.00 g of yeast was then added, and the mixture swirled to mix in the yeast. The stop clock was started.
5. The bung, on which I had placed tubing connecting it to the gas syringe, was placed in the conical flask.

6 Every minute, the volume of carbon dioxide in the gas syringe was recorded.

7 The average volume of carbon dioxide produced per minute was calculated.

8 The experiment was repeated three times and the average rate of carbon dioxide production calculated.

9 The investigation was then carried out at 10 °C, 30 °C, 40 °C, 50 °C and 60 °C.

10 A graph was drawn of the average rate of carbon dioxide production against temperature.

COMMENT

The method is detailed and well written. The student has appreciated that it is important for the sugar solution to reach the temperature being investigated before the yeast is added.

2. OBSERVING, MEASURING AND RECORDING

Learning objective: to make observations and measurements with appropriate precision, record these methodically, and present them in a suitable form.

Questions to ask:

How many different measurements or observations do I need to take?

- ✓ Sufficient readings have been taken to ensure that the data are consistent.
- ✓ It is usual to repeat an experiment to get more than one measurement. If an investigator takes just one measurement, this may not be typical of what would normally happen when the experiment was carried out.
- ✓ When repeat readings are consistent they are said to be **repeatable**.

Do I need to repeat any measurements or observations that are anomalous?

- ✓ An **anomalous result** or **outlier** is a result that is not consistent with other results.
- ✓ You want to be sure a single result is accurate. So you will need to repeat the experiment until you get close agreement in the results you obtain.

- ✓ If an investigator has made repeat measurements, they would normally use these to calculate the arithmetical mean (or just mean or average) of these data to give a more accurate result. You calculate the mean by adding together all the measurements, and dividing by the number of measurements. Be careful though; anomalous results should not be included when taking averages.
- ✓ Anomalous results might be the consequence of an error made in measurement. But sometimes outliers are genuine results. If you think an outlier has been introduced by careless practical work, you should omit it when calculating the mean. But you should examine possible reasons carefully before leaving it out.
- ✓ You are taking a number of readings in order to see a changing pattern. For example, measuring the volume of gas produced in a reaction every 10 seconds for 2 minutes (so 12 different readings). It is likely that you will plot your results onto a graph and then draw a **line of best fit**.
- ✓ You can often pick an anomalous reading out from a results table (or a graph if all the data points have been plotted, as well as the mean, to show the range of data). It may be a good idea to repeat this part of the practical again, but it's not necessary if the results show good consistency.
- ✓ If you are confident that you can draw a line of best fit through most of the points, it is not necessary to repeat any measurements that are obviously inaccurate. If, however, the pattern is not clear enough to draw a graph then readings will need to be repeated.

How should I record my measurements or observations – is a table the best way? What headings and units should I use?

- ✓ A table is often the best way to record results.
- ✓ Headings should be clear.
- ✓ If a table contains numerical data, do not forget to include units; data are meaningless without them.
- ✓ The units should be the same as those that are on the measuring equipment you are using.
- ✓ Sometimes you are recording observations that are not quantities. Putting observations in a table with headings is a good way of presenting this information.

EXAMPLE 2

How many different measurements or observations do I need to take?

A student cut a number of cylinders of tissue from a potato and weighed them, and recorded the mass of each cylinder. Six dishes were set up with each dish containing a different concentration of sucrose. Four potato cylinders were placed into each dish. After one hour, the cylinders were removed, blotted dry and reweighed. The student then calculated the percentage change in mass for each cylinder. The results are shown below.

Concentration of sucrose/M	**Percentage change in mass of potato cylinders/g**				**Average percentage change in mass**	**Texture of potato cylinders (qualitative)**
	Experiment 1	**Experiment 2**	**Experiment 3**	**Experiment 4**		
0.0	+31.4	+33.7	+31.2	+32.5	+42.9	Firm
0.2	+20.9	+33.4	+22.8	+21.3	+21.7	Firm
0.4	−2.7	−1.8	−1.9	−2.4	−2.2	Slightly soft
0.6	−13.9	−12.8	−13.7	−13.6	−13.5	Soft
0.8	−20.2	−19.7	−19.3	−20.4	−19.9	Floppy
1.0	−19.9	−20.3	−21.1	−20.3	−20.4	Very floppy

Δ Table 6.1 Results for Example 2.

In this table of results:

- ✓ the description of each measurement is clear.
- ✓ the units are given.
- ✓ the data are recorded to the same number of decimal places, and decimal points are aligned.
- ✓ calculations of means are recorded to the appropriate number of significant figures.

The student has recorded four measurements for each concentration investigated.

With the exception of the cylinder in Experiment 2 in a concentration of 0.2 M sucrose (highlighted in the table), the repeats show good consistency.

Do I need to repeat any measurements or observations that are anomalous?

The result from the cylinder in Experiment 2 in a concentration of 0.2 M sucrose is not consistent with the other results for this concentration. It an anomalous result and is highlighted in the table. The student has not included this result in the calculation of the mean for this concentration.

EXAMPLE 3

How should I record my measurements or observations?

Here are some results of food tests carried out by an investigator:

Food substance tested	**Colour change on heating with Benedict's solution**
10% glucose solution	blue → green → yellow → orange → red
Biscuit	blue → greenish blue
Grape	blue → green → yellow → orange → red
Honey	blue → green → yellow → orange → red–brown
Potato	remained blue

∆ Table 6.2 Results of some food tests.

Note the clear table headings. The right-hand column doesn't simply say 'colour' but refers to colour *changes*.

COMMENT

Don't forget that some investigations might benefit from including both numerical data and observations, e.g. in the osmosis experiment in Example 2, the student also found it useful to include information on the firmness of the potato cylinders at the end of the experiment.

3. HANDLING EXPERIMENTAL OBSERVATIONS AND DATA

Learning objectives: to analyse and interpret data to draw conclusions from experimental activities which are consistent with the evidence, using biological knowledge and understanding, and to communicate these findings using appropriate specialist vocabulary, relevant calculations and graphs.

Questions to ask:

What is the best way to show the pattern in my results? Should I use a bar chart, line graph or scatter graph?

- ✓ Graphs are usually the best way of demonstrating trends in data.
- ✓ A bar chart or bar graph is used when one of the variables is a **categoric variable**, for example when one of the variables is the type of leaf, or species of organism.
- ✓ A line graph is used when both variables are continuous, e.g. time and temperature, time and volume.
- ✓ Scattergraphs can be shown to show the intensity of a relationship, or degree of *correlation*, between two variables.
- ✓ Sometimes a line of best fit is added to a scatter graph, but usually the points are left without a line.

When drawing bar charts or line graphs:

- ✓ Choose scales that take up most of the graph paper.
- ✓ Make sure the axes are linear and allow points to be plotted accurately. Each square on an axis should represent the same quantity. For example, one big square = 5 or 10 units; not 3 units.
- ✓ Label the axes with the variables (ideally with the independent variable on the *x*-axis).
- ✓ Make sure the axes have units.
- ✓ If more than one set of data is plotted use a key to distinguish the different data sets.

If I use a line graph, should I join the points with a line or a smooth curve?

- ✓ When you draw a line, do not just join the dots!
- ✓ Remember there may be some points that don't fall on the curve – these may be incorrect or anomalous results.
- ✓ A graph will often make it obvious which results are anomalous and so it would not be necessary to repeat the experiment
- ✓ If following the biological rhythms of an organism over a period of time, you should join the data points, point-to-point.

Do I have to calculate anything from my results?

- ✓ It will be usual to calculate means from the data.
- ✓ Sometimes it is helpful make other calculations, before plotting a graph (see Example 2). Other types of calculation include:
  - the energy content of food *per gram* when burning a sample of food
  - the volume of water taken up by a plant from the distance moved by a bubble in a potometer (volume = $\pi r^2 \times$ distance)
  - the density of plants, e.g. as plants per m^2, or frequency of plants or animals, from sampling using a square frame called a quadrat.
- ✓ Investigators also look for numerical trends in data, for example, the doubling of a reaction rate every 10 °C; the doubling of numbers of microorganisms every 20 minutes.
- ✓ Sometimes you will have to make some calculations before you can draw any conclusions.

Can I draw a conclusion from my analysis of the results, and what biological knowledge and understanding can be used to explain the conclusion?

- ✓ You need to use your biological knowledge and understanding to explain your conclusion.
- ✓ It is important to be able to add some explanation, which refers to relevant scientific ideas, in order to justify your conclusion.

EXAMPLE 4

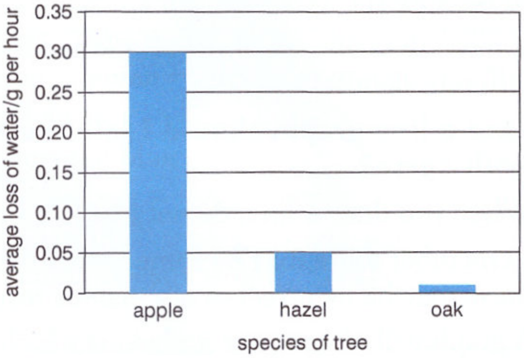
What is the best way to show the pattern in my results?

A student did an experiment to compare the loss of water from leaves of three different species of tree – hazel, lime and oak.

He measured the mass of 10 leaves of similar size and hung the leaves on a line. After three hours, he removed the leaves and measured the masses of the leaves again and calculated the average loss of water in grams per hour.

Species	Average loss of water/g per hour
Apple	0.30
Hazel	0.05
Oak	0.01

Δ Table 6.3 Results of Example 4.



Δ Fig. 6.2 Bar chart showing water loss from different leaves.

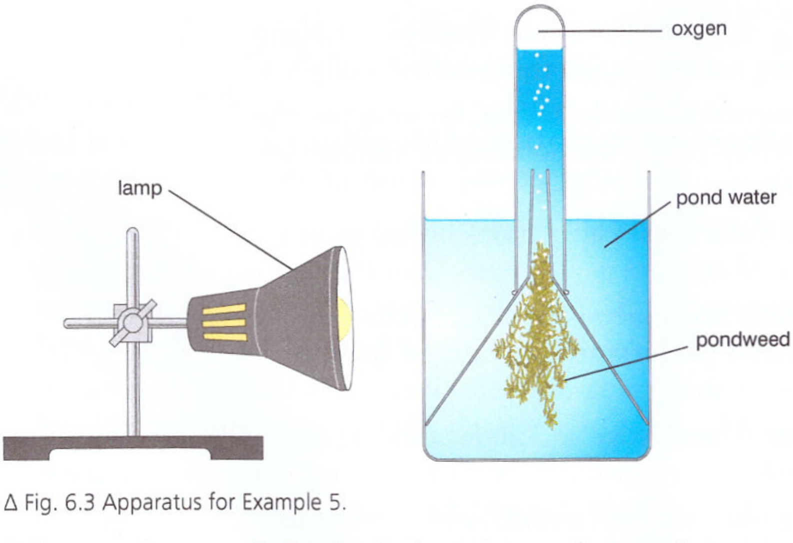
A bar chart or bar graph is used to display the data in this instance, as the type of leaf is a categoric variable.

EXAMPLE 5

What is the best way to show the pattern in my results?

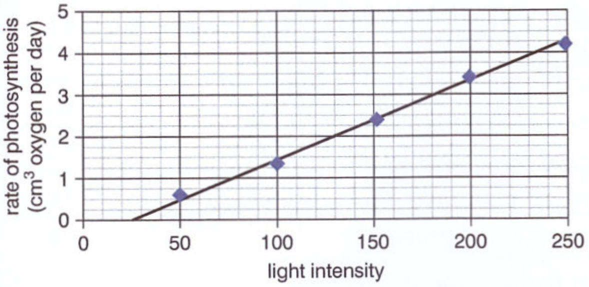
A student investigated the effect of different light intensities on photosynthesis in pondweed.

He measured the oxygen collected over a number of days.



Δ Fig. 6.3 Apparatus for Example 5.

A line graph is needed as both the volume of gas and time are continuous variables.



Δ Fig. 6.4 Experimental results of Example 5.

If I use a line graph, should I join the points with a line or a smooth curve?

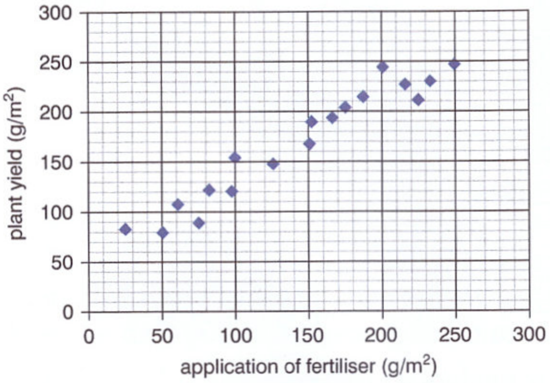
In this case the data fit a straight line most closely. You need to look at the shape that the points make to help you decide how to join them.

EXAMPLE 6

What is the best way to show the pattern in my results?

A student investigated the effect of applying different amounts of fertiliser to plants in the school grounds. He used a scatter graph to display the results he collected.

A scatter graph is most appropriate for displaying these data because each point represents one plant and is unrelated to another point. The results show a trend that should be described in the conclusion.



Δ Fig. 6.5 Experimental results for Example 6.

EXAMPLE 7

If I use a line graph, should I join the points with a line or a smooth curve?

In an investigation on the activity of an enzyme at different temperatures, an investigator obtained a set of results that shows different phases.

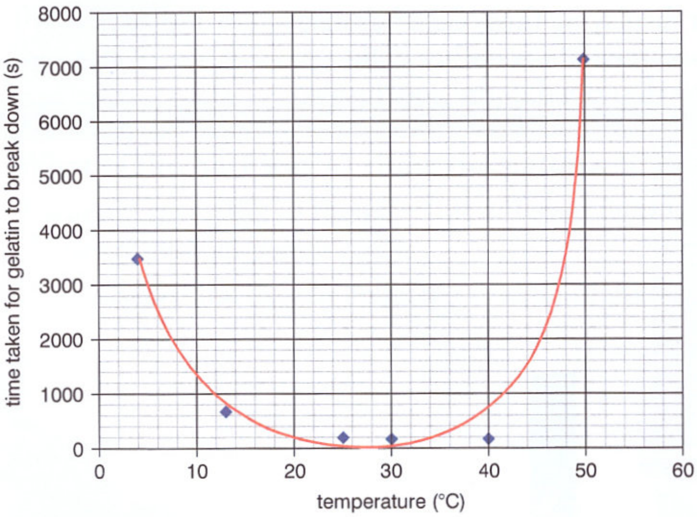
Photographic film is made from a sheet of plastic coated with light-sensitive silver particles bonded by the protein gelatine. When the gelatine is broken down by a protease enzyme, the silver particles fall off, and the film becomes clear.

Photographic film was cut into five strips of equal size, and each strip was placed into a test tube. An identical volume of protease was added to the tubes, and each tube was kept at a different temperature.

The amount of time taken for each strip of film to become clear was measured and recorded.

Temperature/°C	Average time taken for breakdown of gelatine/s
4	3450
13	667
25	175
30	130
40	133
50	7140

∆ Table 6.4 Table of results for Example 7.



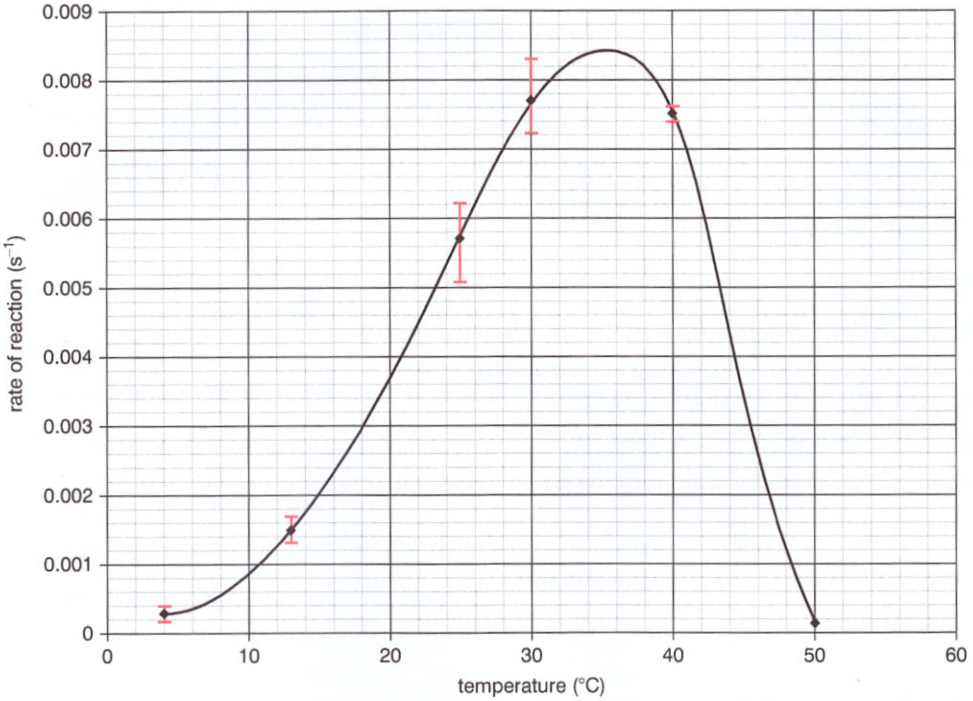
∆ Fig. 6.6 Results for Example 7 with line of best fit plotted.

Do I have to calculate anything from my results?

The trend of how enzyme activity is affected by temperature is not well illustrated by the graph. It is shown better if the *rate of reaction* is calculated and plotted against temperature. The rate is the inverse of the time taken to break down the gelatine, i.e. 1 ÷ the time taken.

Temperature/°C	Average time taken for breakdown of gelatine/s	Rate of breakdown of gelatine (= 1/time)/s^{-1}
4	3450	0.00029
13	667	0.00150
25	175	0.00571
30	130	0.00769
40	133	0.00752
50	7140	0.00014

Δ Table 6.5 Table of results with rate column added.



Δ Fig. 6.7 Rate of reaction for Example 7.

Note that, on this graph, the student has also drawn range bars to show how the data points are arranged around the mean.

Rates can also be calculated by looking at the change in steepness or gradient of a line graph, or part of a graph.

Can I draw a conclusion from my analysis of the results?

The student wrote:

> Enzymes work best at a particular temperature. My graph suggests that the optimum temperature for protease is around 35 °C. At lower temperatures, enzymes work slowly because the molecules have less energy and move around more slowly, so there are fewer successful collisions between enzyme and substrate (gelatine) molecules.

Enzymes work by a lock-and-key mechanism, with the substrate fitting into the enzyme. At temperatures that are too high, the structure of an enzyme will be changed so that it will not work. This change is permanent and the enzyme is said to be denatured.

COMMENT

This is a good, concise conclusion and links the data to the mechanism of enzyme action.

4. PLANNING AND EVALUATING INVESTIGATIONS

4a Planning

Learning objective: to devise and plan investigations, drawing on biological knowledge and understanding in selecting appropriate techniques.

Questions to ask

What do I already know about the area of biology I am investigating, and how can I use this knowledge and understanding to help me with my plan?

- ✓ Think about what you have already learned and any investigations you have already done that are relevant to this investigation.
- ✓ List the factors might affect the process you are investigating.

What is the best method or technique to use?

- ✓ Think about whether you can use or adapt a method that you have already used.
- ✓ A method, and the measuring instruments, must be able to produce **valid** measurements. A measurement is valid if it measures what it is supposed to be measuring.

You will make a decision as to which technique to use based on:

- ✓ The accuracy and precision of the results required. Investigators might require results that are as accurate and precise as possible but if you are doing a quick comparison, or a preliminary test to check a range over which results should be collected, a high level of accuracy and precision may not be required.
- ✓ The simplicity or difficulty of the techniques available, or the equipment required; is this expensive, for instance?
- ✓ The scale, for example using standard laboratory equipment or on a micro-scale, which may give results in a shorter time period.
- ✓ The time available to do the investigation.
- ✓ Health and safety considerations.

What am I going to measure?

- ✓ You need to decide what you are going to measure.
- ✓ You need to choose a range of measurements that will be enough to allow you to plot a graph of your results and so find out the pattern in your results.
- ✓ You might be asked to explain why you have chosen your range, rather than a lower or higher range.
- ✓ The factor you are investigating is called the **independent variable**. A **dependent variable** depends on the value of the independent variable that you select.

How am I going to control the other variables?

- ✓ These are **control variables**. Some of these may be difficult to control. This may be especially difficult if you are carrying out an ecology investigation in the field, where varying factors such as light and temperature are impossible to control.
- ✓ You must decide how you are going to control any other variables in the investigation and so ensure that you are using a fair test and that any conclusions you draw are valid.

What equipment is suitable and will give me the accuracy and precision I need?

- ✓ The *accuracy* of a measurement is how close it is to its true value.
- ✓ Precision is related to the smallest scale division on the measuring instrument that you are using, e.g. when measuring the distance moved by the bubble in Method 3, a rule marked in millimetres will give greater precision than one divided into centimetres only.
- ✓ A set of precise measurements also refers to measurements that have very little spread about the mean value.
- ✓ You need to be sensible about selecting your devices and make a judgement about the degree of precision. Think about what is the least precise variable you are measuring and choose suitable measuring devices. There is no point having instruments that are much more precise than the precision with which you can measure the least precise variable.

What are the potential hazards of the equipment, chemicals, organism and technique I will be using and how can I reduce the risks associated with these hazards?

- ✓ Be prepared to suggest safety precautions when presented with details of a biology investigation.

EXAMPLE 8

You have been asked about the design and planning of an investigation on carbon dioxide production by yeast under different conditions.

What do I already know?

You may have already learned about the role of yeast in the production of alcohol/beer. In the equation for anaerobic respiration of yeast, you can see that in the absence of oxygen, yeast uses sugars for (anaerobic) respiration, producing carbon dioxide and alcohol (ethanol).

As sugar is a reactant in the process, conditions that might affect the production of carbon dioxide on the process include the *concentration of sugar*, and the *type of sugar* may also be a factor.

The chemical reactions involved in this process are controlled by the yeast's enzymes, so you would expect this process to be affected by *temperature*.

Conditions that might be expected to affect the process are therefore:

✓ concentration of sugar

✓ type of sugar

✓ temperature.

You might be questioned on how to measure the effect these factors, or one of these factors, has on carbon dioxide production.

All of these factors are independent variables. The amount of carbon dioxide produced is the dependent variable because it is affected by the independent variables – concentration of sugar, type of sugar and temperature.

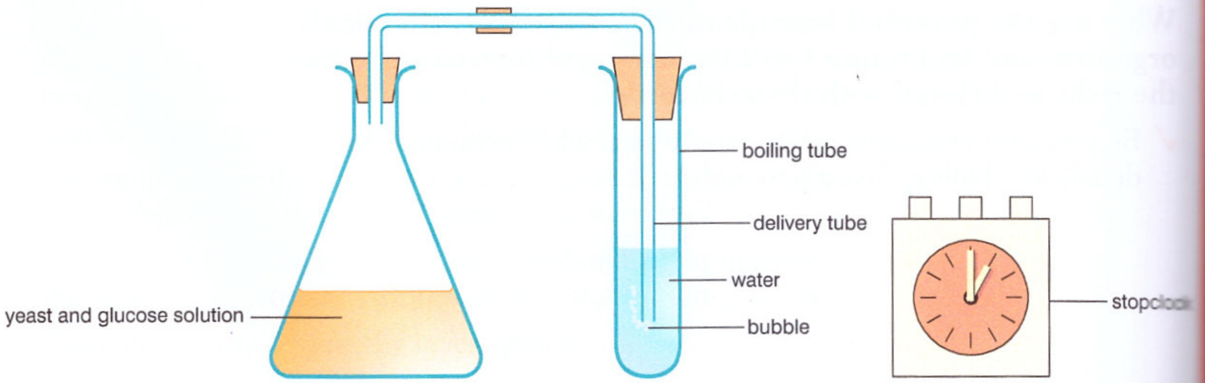
What is the best method or technique to use?

An investigator needs to set up an experiment so that they can measure the carbon dioxide produced by the respiring yeast.

Several methods are available to produce valid measurements.

Method 1

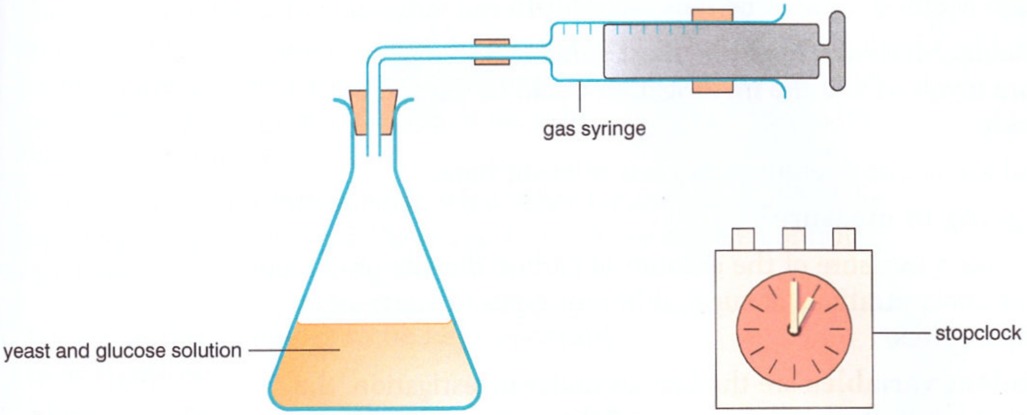
A simple way is to add some yeast to a sugar solution in a conical flask, as shown in the diagram below and count the bubbles produced in given time periods, e.g. every minute, or over a period of time, e.g. one hour.



Δ Fig. 6.8 Apparatus for method 1.

Method 2

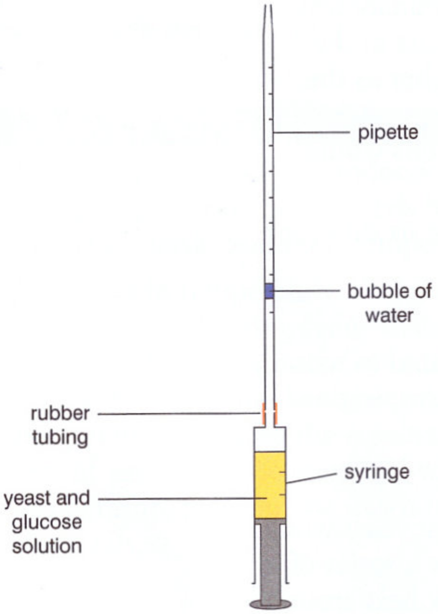
An alternative method is to set up the yeast and sugar solution as before, but this time connect the glass tube to a gas syringe. This time, you can measure the volume of carbon dioxide produced in given time periods, e.g. every minute, or over a period of time, e.g. one hour.


gas syringe
yeast and glucose solution
stopclock

Δ Fig. 6.9 Apparatus for method 2.

Method 3

Another method is based on a smaller scale. The yeast and sugar solution is placed in a syringe, which is connected to a pipette that contains a bubble of water. The movement of the bubble is measured in given time periods, e.g. every minute, or over a period of time, e.g. one hour. It is less suitable for the temperature investigation, however, as it would be inadvisable to immerse the syringes in water baths.


pipette
bubble of water
rubber tubing
syringe
yeast and glucose solution

Δ Fig. 6.10 Apparatus for method 3.

Choosing the method:

- ✓ Accuracy and precision: Methods 2 and 3 would be preferred when accurate and precise results are needed. Method 1 cannot be used to actually measure the volume of carbon dioxide, but would be best for a preliminary test or a quick comparison.
- ✓ Micro-scale: Method 3 might be most suitable here.
- ✓ Time available: Method 3 might be most suitable, as smaller volumes are involved and the investigation could be carried out more quickly.
- ✓ Health and safety considerations are less relevant here.

What am I going to measure?

You need to make a measure of the amount of carbon dioxide produced using different concentrations of sugar, different types of sugar, or at different temperatures.

The **independent variables** are the factors under investigation: the concentration of sugar, the type of sugar and the temperature.

The **dependent variables** are the measurements made: the number of bubbles per minute, the volume of carbon dioxide per minute, or the distance moved by the bubble.

Different concentrations of sugar

A sensible range of sugar concentrations to use might be based on concentrations that yeast might encounter in nature, or might be used to produce different beers in a brewery. The investigator here chose to use concentrations ranging from 0 M to 0.25 M (at intervals of 0 M, 0.05 M, 0.10 M, 0.15 M, 0.20 M and 0.25 M), as a preliminary test showed that these concentrations would give suitable results in the time period allocated. Concentrations chosen were no higher as the investigator realised that these might have an osmotic effect; water could be drawn from the yeast cells by osmosis, and the cells would not function.

The investigator plotted a graph using the results from the six different concentrations to look for a pattern in those results.

Different types of sugar

Here, the investigator decided to use sugars commonly found in nature, or in malted barley in brewing, which yeast might use for respiration. These included fructose, glucose, lactose, maltose and sucrose.

Different temperatures

It would be sensible to choose a range of temperatures that yeast would encounter in nature or in a brewery. Respiration in yeast is a series of enzyme-controlled reactions. In most cases, enzymes work best around 40 °C, and cease to function above around 60 °C. It was decided, therefore, to measure carbon dioxide production at five different temperatures (10 °C, 20 °C, 30 °C, 40 °C, 50 °C and 60 °C). Again, this would be sufficient to allow the investigator to plot a graph of results and so find any pattern in the results.

How am I going to control the other variables?

The investigator must ensure that any differences in carbon dioxide production must be the result of, in the different investigations, sugar concentration, type of sugar and temperature, and not the result of some other factor. In other words, it must be a fair test and produce valid measurements.

So, the investigator must decide what other factors could affect the experiment and try to keep these constant. These are the control variables.

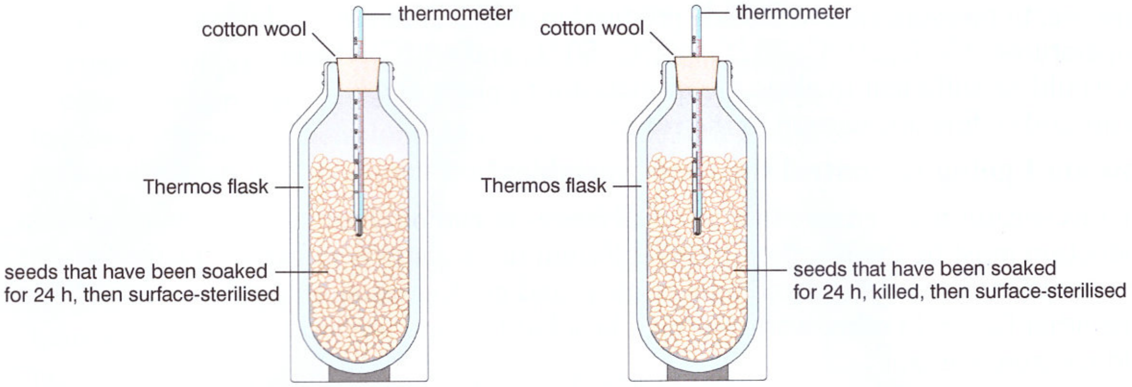
Factor under investigation/ independent variable	**Factors to be kept constant**				
	Yeast concentration	**Sugar concentration**	**Type of sugar**	**Temperature**	**Length of investigation**
Sugar concentration	Yes	No – varies	Yes	Yes	Yes
Type of sugar	Yes	Yes	No – varies	Yes	Yes
Temperature	Yes	Yes	Yes	No – varies	Yes

Δ Table 6.6 Variables in Example 8.

EXAMPLE 9

In this experiment, the production of heat from germinating seeds is being investigated. Some seeds have been placed in an insulated flask (Thermos flask) and their temperature measured over a period of time.

But a rise in temperature alone would not be sufficient to demonstrate that it is the respiring seeds that are causing this rise. Some other factor could be involved. So an identical experiment is set up, but this time with seeds that have been killed. So any change in the temperature must be the result of the living seeds' respiration. Both sets of seeds are also sterilised with disinfectant so that any temperature rise can't be down to the growth of microorganisms on the seeds.


cotton wool
thermometer
Thermos flask
seeds that have been soaked for 24 h, then surface-sterilised
cotton wool
thermometer
Thermos flask
seeds that have been soaked for 24 h, killed, then surface-sterilised

Δ Fig. 6.11 Apparatus for Example 9.

What equipment is suitable and will give me the accuracy and precision I need?

You now know what you will need to measure and so can decide on your measuring devices.

Referring back to Example 8:

Measurement	Quantity required	Equipment
Mass of yeast	1.00 g	Balance measuring up to two decimal places
Volume of sugar solution	100 cm^3	100 cm^3 volumetric flask
Temperature	10–60 °C	Thermometer, with 1 °C precision
Time	One minute intervals	Stop watch (1 s precision)

Δ Table 6.7 Suitable equipment for experiment.

You will need to be sensible about selecting your equipment and make a judgement about the degree of accuracy. The accuracies of equipment need to be comparable. It would be not appropriate to measure the yeast that was put in every conical flask accurately without measuring the volume of sugar solution poured onto each flask to a similar level of accuracy.

What are the potential hazards of the equipment and how can I reduce the risks?

In Example 8, the chemical hazards are as follows:

Fructose solution	LOW HAZARD
Glucose solution	LOW HAZARD
Lactose solution	LOW HAZARD
Maltose solution	LOW HAZARD
Sucrose solution	LOW HAZARD
Yeast, dried	LOW HAZARD

These indicate that there are no specific hazards the investigator needs to be aware of. However, when handling *any* chemicals, it would be sensible to wear eye protection.

In terms of the equipment and technique, the major hazards are:

- ✓ handling hot liquids (at 50 °C and 60 °C)
- ✓ when connecting tubing together
- ✓ possible contact between water and electrical sockets.

4b Evaluating

Learning objective: to evaluate data and methods.

Questions to ask:

Do any of my results stand out as being inaccurate?

- ✓ You need to look for any anomalous results or outliers that do not fit the pattern.
- ✓ You can often pick out anomalous results from a results table (or from a graph if all the data points have been plotted, as well as the mean, to show the range of data, provided the investigator has not included this result in the calculation of the mean for this concentration). It may be a good idea to repeat this part of the practical again, but it is not necessary if the other results show good consistency.

What reasons can I give for any inaccurate results?

- ✓ When answering questions like this, it is important to be specific. Answers such as 'experimental error' will not score any marks.
- ✓ It is often possible to look at the practical technique and suggest explanations for anomalous results.
- ✓ When you carry out the experiment, you will have a better idea of which possible sources of error are more likely.
- ✓ Try to give a specific source of error and avoid statements such as 'the measurements must have been wrong'.

Your conclusion will be based on your findings, but must take into consideration any uncertainty in these introduced by any possible sources of error. You should discuss where these have come from in your evaluation.

Error is a difference between a measurement you make, and its true value.

The two types of errors are:

- ✓ random error
- ✓ systematic error.

With **random error**, measurements vary in an unpredictable way. This can occur when the instrument you are using to measure lacks sufficient precision to indicate differences in readings. It can also occur when it is difficult to make a measurement. If two investigators measure the height of a plant, for instance, they might choose different points on the compost, and the tip of the growing point to make their measurements.

With **systematic error**, readings vary in a controlled way. They're either consistently too high or too low. One reason could be down to the way you are making a reading, for example taking a burette reading at the wrong point on the meniscus, or not being directly in front of an instrument when reading from it.

An investigator *should not* discuss in an evaluation problems introduced by using faulty equipment, or by using the equipment inappropriately. These errors can, or could have been, eliminated, by:

- ✓ checking equipment
- ✓ practising techniques before the investigation, and taking care and being patient when carrying out the practical.

Overall, was the method or technique I used accurate enough?

- ✓ If your results were good enough to provide a confident answer to the problem you were investigating, the method probably was good enough.
- ✓ If you realise your results are not precise, it may be you have a **systematic error** (an error that has been made in obtaining all the results). A systematic error would indicate an overall problem with the experimental method.
- ✓ If your results do not show a convincing pattern, then it is fair to assume that your method or technique was not precise enough and there may have been a **random error** (i.e. measurements vary in an unpredictable way).

If I were to do the investigation again, what would I change or improve upon?

- ✓ Having identified possible errors, it is important to say how these could be overcome. Again you should try and be absolutely precise.
- ✓ When suggesting improvements, do not just say 'do it more accurately next time' or 'measure the volumes more accurately next time'.
- ✓ For example, if you were measuring small volumes, you could improve the method by using a burette to measure the volumes rather than a measuring cylinder.
- ✓ Other errors arise from accuracy of measurement. And investigations can also often be improved by extending the range (e.g. temperature, time, pH, etc.) over which it is carried out.

Do any of my results stand out as being inaccurate?

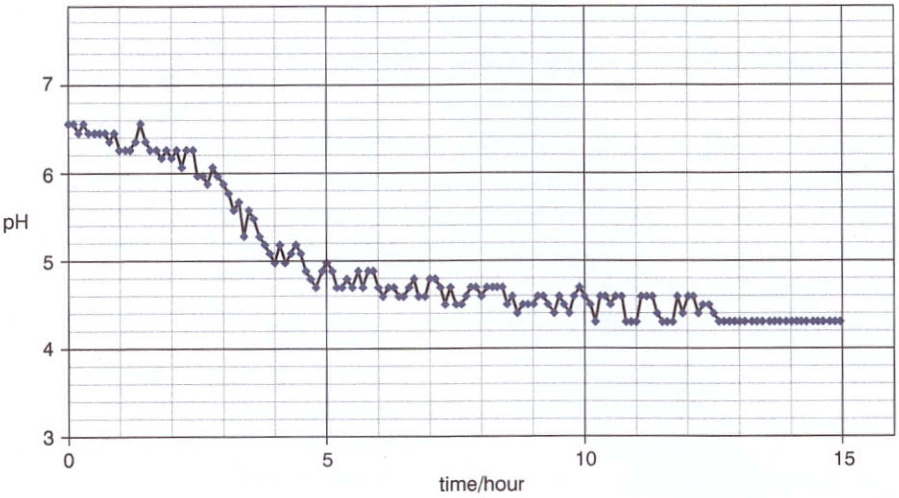
In Example 2, the results from the cylinder in Experiment 2 in a concentration of 0.2 M sucrose are not consistent with the other results for this concentration. The **anomalous result** or **outlier** is highlighted in the table.

EXAMPLE 10

What reasons can I give for any inaccurate results?

In this example, the pH of yoghurt was monitored during its production using a data logger. The data logger gave very precise, consistent readings. First, it had to be set, or *calibrated*, using solutions of known pH (called buffers).

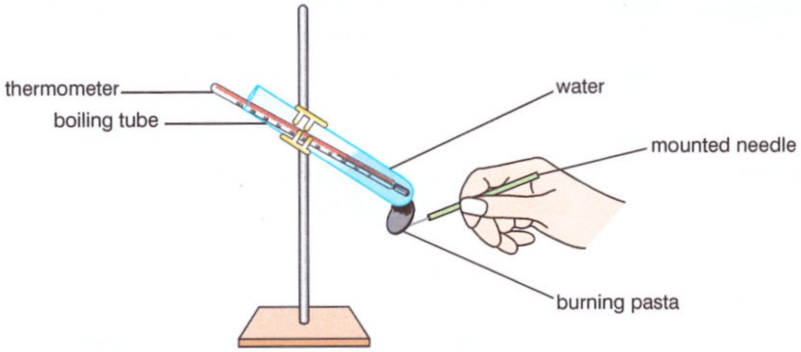
In Example 2, it's possible that the potato cylinder had not been blotted dry properly before its mass was measured.



Δ Fig. 6.12 Experimental results for Example 10.

EXAMPLE 11

In an investigation on the energy content of food, an investigator used the apparatus below to find the energy content of a piece of pasta.



Δ Fig. 6.13 Apparatus for Example 11.

Was the method or technique I used accurate enough?

The value obtained by the investigator was 1272 joules of energy per gram of pasta. This value was much lower than the value of 13 440 joules per gram of pasta printed on the packet.

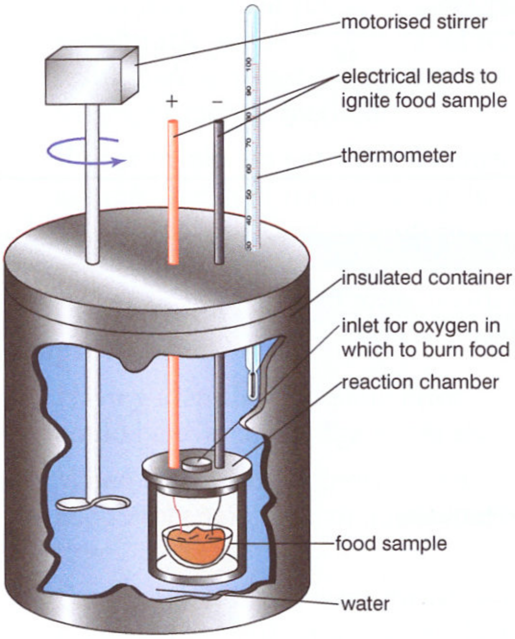
The main problem with this method is that it relies on the transfer of all the chemical energy in the food to heat energy, which is used to warm the water. But using this equipment, the transfer is nowhere near 100 percent. Reasons for this are:

- ✓ conversion of the chemical energy to other forms of energy
- ✓ incomplete combustion of the food
- ✓ poor transfer of heat from the burning pasta to the water.

Measurements of the temperature rise may also be inaccurate because the heat energy is not evenly distributed through the water.

If I were to do the investigation again, what would I change or improve on?

It is possible to improve the accuracy of energy values of food in the school laboratory by modifying the method above or using different equipment. The transfer of heat to the container holding the water (in this case, a boiling tube) can be improved, and the container could also be insulated. Many investigators use a device called a bomb calorimeter to overcome these problems. The food is burned inside the bomb calorimeter.


motorised stirrer
electrical leads to ignite food sample
+
–
thermometer
insulated container
inlet for oxygen in which to burn food
reaction chamber
food sample
water

Δ Fig. 6.14 Improved apparatus for Example 11.

Glossary

absorption The movement of digested food molecules from the alimentary canal into the blood.

accommodation How the lens of the eye changes so that objects at different distances are focused on the retina.

acid rain Rain that contains higher than normal concentrations of dissolved acidic gases, such as sulfur dioxide and nitrogen oxides, which causes the rain to have a lower pH than normal.

acrosome A bag of enzymes at the front of a sperm cell that makes it possible for the sperm nucleus to enter the egg cell.

active site The space in an enzyme into which the substrate molecule fits.

active transport The movement of molecules across a cell membrane using energy from respiration; movement is often against a concentration gradient.

adaptive feature A feature that helps an organism to survive well in its environment.

adrenaline The hormone produced by the adrenal glands that prepares the body for action.

aerobic respiration Respiration (the breakdown of glucose to release energy) using oxygen.

AIDS Acquired immunodeficiency syndrome, caused by the human immunodeficiency virus.

alimentary canal The tubular part of the digestive system, from mouth to anus.

allele One version of a gene, producing one form of the characteristic that the gene codes for.

alveoli The tiny bulges of the air sacs in lungs where gases diffuse between the air in the lungs and the blood (singular: alveolus).

amino acid The basic unit of a protein.

amniotic fluid Fluid surrounding the developing fetus in the uterus.

amniotic sac The tough membrane surrounding the developing fetus and amniotic fluid in the mother's uterus.

amylase An enzyme that digests starch.

anaerobic respiration Respiration (the breakdown of glucose to release energy) without oxygen (also called *fermentation*); in animal cells produces lactic acid; in plant cells and yeast produces ethanol and carbon dioxide.

anther The male part of flower that produces pollen.

antibiotic resistance Resistance in bacteria to the effect of an antibiotic that normally kills them.

antibiotics Drugs used to treat infections caused by bacteria, fungi or protoctists (mainly bacteria), but not those caused by viruses.

antibodies Chemicals produced by some white blood cells, which attack pathogens.

aorta The largest artery, which receives blood from the left ventricle of the heart.

arteriole Small blood vessel that connects an artery to a capillary.

artery Blood vessel that carries blood away from the heart.

asexual reproduction Production of young without fertilisation.

assimilation When absorbed food molecules are taken into cells and used to make new substances.

atrium (plural atria) One of two chambers of the heart that receive blood from veins and pump it into the ventricles.

auxin A plant hormone that controls growth of roots and shoots.

balanced diet The intake of food that supplies all the protein, fat, carbohydrate, vitamins and minerals that the body needs in the right amounts.

Benedict's reagent Solution that changes colour in the presence of reducing sugars, used to test for their presence in a food sample.

biconcave A shape in which the middle is pressed inwards, making a red blood cell thinner in the middle than at the edges.

bile The liquid produced by the liver and stored in the gall bladder, which is highly alkaline and emulsifies lipids.

biodiversity The range of variation in species in an area.

biological catalyst A catalyst of reactions inside living organisms.

biomass The mass of a living organism.

biotechnology The use of organisms to make products.

biuret test The test used to indicate the presence of protein in a food sample.

bladder The organ of the excretory system that stores urine from the kidneys until it is released to the environment.

bronchioles The tiny tubes in the lungs that carry air to the alveoli.

bronchitis A disease of the lungs that produces a hacking cough as a result of damage to the cilia by smoking or infection.

bronchus The division of the trachea as it joins to the lungs. (Plural: bronchi)

cancer A disease caused by uncontrolled division of cells.

canine A tooth with a pointed shape, behind the incisors in the mouth, which holds food while other teeth bite and chew.

capillary Smallest blood vessel, found within every tissue, which exchanges substances with the cells.

carbohydrate A large molecule, such as starch or glycogen, made of many simple sugars.

carbon cycle How the element carbon cycles in different forms between living organisms and the environment.

carnivore An animal that eats animals.

carpel The female structure in flowers that contains one or more ovaries and their stigmas and styles.

catalyst A substance that increases the rate of a chemical reaction, such as an enzyme.

cell membrane The structure surrounding cells that controls what enters and leaves the cell.

cell wall A layer of cellulose that surrounds plant cells, giving them support and shape. Bacterial cells also have a cell wall outside the cell membrane.

cellular respiration See *respiration*.

central nervous system The brain and spinal cord.

cervix The narrow passage between the uterus and the vagina.

chemical digestion The breakdown of large molecules into smaller ones using enzymes.

chlorophyll The green chemical in chloroplasts that captures light energy for photosynthesis.

chloroplast An organelle found in plant cells and some protoctist cells that can capture energy from light for use in photosynthesis.

chromosome A long DNA molecule that is found in a cell nucleus.

cilia Tiny hairs that project from a cell surface and that move things across the cell surface.

ciliated cell A cell that has cilia on its surface.

circulatory system The organ system that transports substances around the body.

climate change Change to wind, rainfall and temperature as a result of the greenhouse effect.

cohesion Where molecules stick together, such as water molecules in the xylem of a plant.

combustion Burning, such as that of fossil fuels.

community All the organisms that live in the same habitat.

complementary Being similar but opposite, like the shape of the space in an enzyme and the shape of its substrate.

concentration gradient The difference in the amount of a substance between two areas; diffusion is usually down the concentration gradient: molecules move from the area of high concentration to the area of low concentration.

condom A rubber sheath placed over the erect penis to act as a mechanical barrier against sperm.

constipation The slow movement of digested food through the intestines and rectum as a result of there being too little fibre in the food for peristalsis to be effective.

consumer An organism that gets its food by eating other organisms; an animal.

continuous variation Variation in a feature that can have any value (e.g. height).

core temperature The temperature around the major organs of the heart and liver.

cornea The front part of the eye, where most light focusing occurs.

coronary heart disease Diseases such as angina, high blood pressure or heart attack, caused by the partial or complete blockage of a coronary artery, such as by cholesterol.

crenated the contraction of a cell in response to a more concentrated solution, due to the movement of water to the outside of the cell by osmosis.

cuticle A waxy layer that covers leaves, particularly the upper surface, to reduce water loss from the leaf.

cytoplasm The jelly-like liquid inside the cell that contains the organelles and where many chemical reactions take place.

daughter cell A cell produced by division of a parent cell.

decomposer An organism that feeds on dead plants or animals, or animal waste.

deforestation The destruction of large areas of forest or woodland.

denature When an enzyme stops working, which may be the result of high temperature or pH change.

dentine The main layer of tooth below the enamel and softer than enamel.

deoxygenated Lacking in oxygen.

deoxyribonucleic acid See *DNA*.

depressant A drug that slows down the rate of response of the body.

diaphragm (respiratory system) A sheet of tissue situated below the lungs that controls breathing.

dichotomous key A series of pairs of questions

diffusion The net movement of molecules along a concentration gradient from a region of higher concentration to a region of lower concentration; it is a passive process (it does not require energy).

digestion The breakdown of large food molecules into smaller molecules.

digestive enzyme An enzyme found in the digestive system.

diploid A cell that contains two sets of chromosomes.

discontinuous variation Variation in a feature that can have only a particular number of possibilities (e.g. eye colour, fur colour, sex).

DNA (deoxyribonucleic acid) The chemical that forms chromosomes and carries the genetic code.

dominant An allele that only needs to be present on one chromosome of a pair to produce its version of the characteristic.

double circulation A circulatory system, as in humans, where the blood passes through the heart to be pumped first to the lungs, then returned to the heart to be pumped to the rest of the body.

ecosystem The community of organisms and their environment in an area that interact together.

effector An organ that responds to the nervous system, such as a muscle or a gland.

egestion The removal of undigested material from the body (faeces) (compare with *excretion*).

egg cell The female sex cell.

embryo Developing young, in which cell division and differentiation are taking place rapidly. The stage before a fetus.

emphysema A disease of the lungs caused by damage to alveoli, which reduces the area for gas exchange in the lungs.

emulsify To break up large droplets of a lipid in an aqueous solution into smaller droplets.

enamel The hard outer covering of a tooth that protects the softer layers inside the tooth.

endocrine gland An organ that produces a hormone.

enzyme A protein that acts as a biological catalyst, changing the rate of reactions in the body.

epidermis The layer of cells on the outer surface of a body or organ, such as a leaf.

eutrophication The addition of nutrients to water, which may lead to water pollution.

evaporation When particles in a liquid (e.g. water) gain enough energy to move fast enough and become a gas (as in water vapour).

evolution Change over time in the adaptive features of a population or species through the process of natural selection in response to changes in their environment.

excess More than is needed.

excretion Removal of waste (often toxic) substances, such as carbon dioxide and urea, in animals that have been produced from chemical reactions inside the body.

expiration Breathing out.

extinct When all individuals of a species have died.

faeces The undigested material that remains after digestion of food in humans.

famine Starvation of many people in an area as a result of extreme shortage of food.

fat A solid lipid.

fatty acid One of the basic units of a lipid, along with glycerol.

femidom The female equivalent of a condom, which prevents sperm entering the woman's body.

feminisation When male organisms show female features, for example after exposure to female sex hormones.

fertile An organism that can breed and produce offspring.

fertilisation Joining of male and female sex cells.

fetus The name given to the developing baby in the uterus.

fibre Plant material that is difficult to digest and keeps the food in the alimentary canal soft and bulky, aiding peristalsis. Also called *roughage*.

flaccid Wilting caused by loss of water by osmosis. The vacuole shrinks and does not push against the cell wall to give the plant support.

flagellum Large cell structure that moves back and forth to move the cell, such as the 'tail' of a sperm cell.

fluoride A soluble chemical that hardens tooth enamel; may be added to public water supplies to reduce risk of tooth decay.

food chain diagram A diagram that shows the transfer of energy from organism to organism by ingestion.

food web diagram A diagram showing the feeding relationships between organisms in the same community.

fossil fuel Fuel formed from organic material, such as peat, coal and oil.

gamete A sex cell.

gas exchange The exchange of gases between the air and the body across a gas exchange surface such as the lungs or a leaf.

gene A small section of DNA that codes for a protein.

gene mutation A change in base sequence of a gene.

genetic code The sequence of bases along one strand of DNA.

genetic diagram A diagram that displays how a characteristic may be inherited by offspring from the parents: alleles.

genetic variation The differences in genes and alleles cause by gene mutations.

genotype The genetic code of an organism.

germination The start of plant growth from a seed, which only occurs when there is the right amount of oxygen and water, and an appropriate temperature.

glycerol One of the basic units of a lipid, along with fatty acids.

glycogen Large carbohydrate that is stored in liver cells for use as an energy source.

graticule The scale viewed through a microscope, used to calculate the observed size of a structure.

gravitropism A plant's growth in response to gravity.

growth The permanent increase in body size and dry mass of an organism, usually from an increase in cell number or cell size (or both).

haemodialysis Artificial cleansing of the blood by passing it through dialysis fluid where diffusion of urea, excess proteins and water can occur.

haemoglobin The red chemical in red blood cells that combines reversibly with oxygen.

haploid A cell that contains only one set of chromosomes, such as gametes.

heart The organ of the circulatory system that pumps blood.

heart attack When the heart stops working, due to a blockage of a coronary artery.

heart rate The number of heart beats in a given time, e.g. beats per minute.

herbicide A chemical that kills plants, often containing plant hormones for killing weeds.

herbivore An animal that eats plants.

heroin A dangerously addictive drug with powerful depressant effects.

heterozygous Where the two alleles for a gene are different in the genotype.

HIV Human immunodeficiency virus, transmitted during sexual intercourse, by blood, through the placenta or in breast milk, which causes AIDS.

homeostasis Keeping the internal environment of the body within safe limits.

homozygous Where the two alleles for a gene are the same in the genotype.

hormonal system The chemical response system of the body to changes in the environment.

hormone A chemical substance produced by a gland, resulting in a change in another part of the body.

humidity A measure of the concentration of water molecules in the air.

hypha A single thread of fungal mycelium (plural *hyphae*).

immune system The system of the body that protects the body against infection; includes white blood cells.

implantation When the embryo settles into the thickened uterus lining.

incisor A flat-bladed tooth type at the front of the mouth, for biting off pieces of food.

ingestion The taking of food into the alimentary canal.

inheritance the passing of inherited characteristics from one generation to the next.

insecticide A chemical used to kill insect pests.

insoluble A substance that does not dissolve.

inspiration Breathing in.

insulin The hormone produced by the pancreas that controls blood sugar concentration.

intercostal muscles Muscles between the ribs that help with breathing.

involuntary Done without thought or control from the central nervous system, such as a reflex response.

ionising radiation Radiation, such as gamma rays, X rays and ultraviolet radiation, that can damage cells and produce mutations in genes.

kidney Organ that removes unwanted substances from the blood to produce urine.

kinetic energy The energy carried by moving molecules.

kwashiorkor Protein energy malnutrition, usually seen in young children who have a diet that contains little protein.

labour The stage at the end of pregnancy when the muscles of the uterus wall start to contract strongly to push the baby out of the mother's body.

lactase The enzyme that breaks down lactose, the sugar found in milk, which can cause digestive problems in some people.

lacteal Tubes of the lymphatic system that carry fat droplets from the digestive system around the body.

larynx The 'voice box' at the top of the trachea, which produces sounds when air moves through it, e.g. when speaking.

leaching The loss of dissolved mineral nutrients in soil water as it soaks deep into the ground beyond the reach of plant roots.

lens The structure in the eye that produces fine focusing of an image on the retina.

lipase An enzyme that digests lipids (fats and oils).

lipid Molecule made from fatty acids and glycerol.

lungs Organs in the human body where gas exchange takes place.

lymphatic system A system of tubes that collects tissue fluid from the tissues and returns it to the blood system near to the heart.

magnification The amount by which a microscope increases the observed size of a structure compared with its actual size: calculated by multiplying the eyepiece magnification with the objective magnification.

malnutrition Not getting the right amounts and balance of nutrients and other essential substances in the diet, including a diet that has too much or too little of any of these.

marasmus A disease caused by protein deficiency causing a child's weight to be low for its age.

mechanical digestion The breaking up of food into smaller pieces through biting and chewing by teeth.

meiosis The form of cell division that produces four haploid, and genetically different, cells from a diploid parent cell; produces gametes.

menstrual cycle The continuous sequence of events in a woman's reproductive organs; each cycle of ovulation (ripening and release of an egg) and menstruation (shedding of the unwanted uterus lining) takes about 28 days and is controlled by the hormones oestrogen and progesterone.

metabolism All the reactions that occur inside the body that keep an organism alive.

microvilli Tiny finger-like extensions of the cell membrane of the surface cells of villi.

mineral (mineral ion) Nutrients that plants and animals need in small amounts, such as nitrates that are needed for making amino acids.

mitochondria Cell structures in which respiration takes place.

mitosis The form of cell division that produces two identical diploid daughter cells from a diploid body cell, used for growth and repair in the body and in asexual reproduction.

molar A tooth type found at the back of the mouth that has a large grinding surface for chewing.

monohybrid cross The inheritance of a characteristic produced by one gene.

motor neurone (also called *effector neurone*) A nerve cell that carries electrical impulses from the central nervous system to an effector.

movement The ability to change the position of all or some of the body.

mucus Slimy liquid that is produced by cells lining the trachea, bronchi and bronchioles.

multicellular An organism that has a body which contains many cells.

mutagen A chemical that produces mutations in genes.

mutation A change in the genetic code of an organism.

mycelium A mass of hyphae that forms the body of a fungus.

natural selection The influence of the environment on survival and/or reproduction, such that some characteristics are more successful at producing offspring than others.

negative feedback Where a change in a stimulus causes the body to respond by reversing that change, e.g. in controlling body temperature.

nerve A bundle of nerve cells.

net movement The sum of all the movements in different directions, e.g. the movement of all the particles being considered in diffusion or osmosis.

neurone A nerve cell.

nicotine The addictive chemical in tobacco smoke.

non-biodegradable Something that does not break down quickly in the environment.

nucleus The organelle in plant and animal cells that contains the genetic material.

nutrition The taking in of nutrients to the body from the environment.

obesity A condition of the body that has large amounts of fat.

oestrogen A hormone produced by the ovaries that helps to control the menstrual cycle and produces secondary sexual characteristics in girls.

oil A liquid lipid.

omnivore An animal that eats both plants and animals.

optic nerve A nerve in the eye which carries electrical impulses from the retina to the brain.

optimum pH The pH at which an enzyme works best.

optimum temperature The temperature at which an enzyme works best.

osmosis The net movement of water molecules through a partially permeable membrane, from a solution that has a higher concentration of water molecules (a dilute solution) to one that has a lower concentration of water molecules (a more concentrated solution).

ovary (in plants and humans) A structure that contains egg cells.

oviduct A tube that carries the egg released from the ovary to the uterus; where fertilisation occurs.

ovulation When an egg is released by an ovary.

ovule Female structure in a flower that contains one egg cell.

oxygen debt The need for oxygen after anaerobic respiration to break down lactic acid.

oxygenated Containing a lot of oxygen.

palisade cell Cells in the upper part of a leaf that contain the most chloroplasts and carry out most of the photosynthesis in a leaf.

pancreas The organ that produces the hormone insulin.

partially permeable The condition of a membrane that lets some substances pass through but not others.

passive immunity Introducing antibodies against a pathogen, either by injection, or mother-to-baby contact through the placenta or breast milk, which gives only short-term protection against the pathogen.

passive The opposite of *active*, happening without the need for additional energy.

pathogen A disease-causing organism.

pectinase The enzyme that breaks down pectin in plant cell walls, and so helps to release more juice from plant cells in the production of fruit juice.

penicillin The antibiotic produced by the fungus *Penicillium*.

peripheral nervous system All the nerves that are not part of the central nervous system.

peristalsis The rhythmic muscular contractions of the alimentary canal that moves food from mouth to anus.

pest An organism that is causing a problem.

pesticide A chemical used to kill pests.

phagocyte A type of white blood cell that engulfs and destroys pathogens.

phagocytosis To flow and engulf, as when phagocytes engulf pathogens.

phenotype The visible characteristics of an organism as a result of its genes.

phenotypic variation Variation in visible characteristics.

phloem The plant tissue that carries sucrose through the veins of a plant.

photosynthesis The process carried out in plant cells that makes sugars by combining carbon dioxide and water molecules using energy from light.

phototropism Growth of a plant in response to light.

phylum A group of classes that share key features.

placenta A structure formed by the developing fetus that attaches to the wall of the mother's uterus and across which substances are exchanged between the mother and fetus.

plasma The liquid, watery part of blood that carries dissolved food molecules, urea, hormones, carbon dioxide and other substances around the body and also helps to distribute heat.

plasmolysed A plant cell in which the cell membrane is pulling way from the cell wall due to lack of water.

platelet Fragment of a much larger cell that causes blood clots to form at sites of damage in blood vessels.

pollination The process in which pollen from one flower is transferred to another flower, before fertilisation can take place.

pollution The introduction of potentially harmful or toxic substances that cause damage to the environment, people and other organisms, often as a result of adding chemicals to the air, water or land.

population A group of organisms of the same species living in a particular habitat.

premolar A tooth type, found behind the canines, that helps with cutting off food and has a small grinding surface for chewing.

producer An organism that produces its own food; for example, plants using energy transferred from light in photosynthesis to produce glucose.

product A molecule that is formed during a reaction.

protease An enzyme that digests proteins.

protein A large molecule that is made of many amino acids joined together.

protein energy malnutrition A condition caused by a diet that contains little protein, often causing kwashiorkor.

protein synthesis The process in which proteins are made inside a cell.

pulp cavity The soft layer in the middle of the tooth containing the blood vessels and nerves.

pupil Opening in the eye that lets light reach the retina.

pyramid of biomass A diagram that shows the biomass in different trophic levels of a food chain; often a pyramid shape.

pyramid of numbers A diagram that shows the number of individual organisms in different trophic levels of a food chain; often a pyramid shape.

receptor organ An organ that receives information about the environment (such as eye or ear) and responds by stimulating a neurone.

recessive An allele that must be present on both chromosomes of a pair to produce its version of the characteristic.

red blood cell Blood cell that contains the red protein haemoglobin, which carries oxygen.

reduction division Cell division that reduces the number of chromosomes, such as meiosis.

reflex An automatic response to a stimulus.

reflex arc The pathway of neurones that an electrical impulse follows during a reflex response.

relay neurone A nerve cell in the central nervous system (also called *intermediate* or *connector neurone*) that forms a connection between other neurones.

reproduction The process of creating new members of a species.

respiration The chemical process in which glucose is broken down inside the mitochondria in cells, releasing energy and producing carbon dioxide and water.

retina The layer of light-sensitive cells at the back of the eye.

root hair cell A cell in the epidermis of roots that has a long extension of cytoplasm, where uptake of substances from soil water occurs.

secretion The release of chemicals that have been made inside the cell into the fluid outside the cell.

seed The structure formed from an ovule that contains the plant embryo and food stores.

selective breeding The breeding together of organisms that have desirable features.

sense organ An organ that responds to a stimulus by causing an electrical impulse in a neurone.

sensitivity The detection of changes (stimuli) in the surroundings by a living organism, and its responses to those changes.

sensory neurone A nerve cell that carries electrical impulses from a receptor to the central nervous system.

sewage Human waste, faeces and urine.

sex chromosome A chromosome that affects the sex of the individual, e.g. for humans XX in women and XY in men.

sexual reproduction Production of new individuals by the fusion of a male and a female gamete.

sexually transmitted infection (STI) Infection transmitted by sexual intercourse, such as HIV.

simple sugar A basic sugar unit (e.g. glucose) that can join together with other sugar units to make large carbohydrates, such as starch and glycogen.

sink Part of a plant where a substance is converted into other substances for growth or storage, or is used – for example, sucrose is broken down to glucose and used in respiring cells.

soil erosion The washing away of soil as a result of wind and rainfall when there is little vegetation to hold on to the soil.

soluble Dissolves easily in a solvent, such as water.

source Where something is produced or enters the body, such as photosynthesising cells for glucose.

specialisation When a cell develops special features that help it work in a particular way.

species A group of organisms that share many features and can interbreed to produce fertile offspring.

specific Limited, usually to one or a few. For example, enzymes are specific because they only work with one or a few similar substrates.

sperm cell Male gamete in animals.

spongy mesophyll The layer of cells in the lower part of the leaf in which there are many air spaces, so increasing the internal surface-area-to-volume ratio.

stamen The male structure in flowers that contains the anther.

starch A complex carbohydrate made from many glucose units.

starvation Eating too little food to supply the body with its need for energy and nutrients.

stem cell A cell that is able to divide and produce most kinds of differentiated cell.

stigma The female structure in flowers to which pollen grains attach in pollination.

stimulus A change in the internal or external environment that produces a response by an organism.

stomata Tiny holes in the surface of a leaf (mostly the lower epidermis), which allow gases to diffuse into and out of the leaf. (Singular: stoma)

style The structure that supports the stigma in a flower.

substrate A molecule that fits into an enzyme molecule at the start of a reaction.

sucrose Common sugar that is formed of pairs of glucose units.

synapse Where two neurones connect.

synthesis The building of larger molecules from smaller ones, such as the formation of proteins from amino acids.

target organ An organ that is affected by a hormone.

tension A 'pull', such as the pull created by the cohesion of water molecules in xylem.

testis The site of production of sperm in men.

testosterone The male sex hormone that is produced in the testes.

toxic Poisonous.

trachea The tube leading from the mouth to the bronchi, sometimes called the windpipe.

translocation The movement of dissolved substances, such as sucrose and amino acids, through the phloem tissue of a plant.

transpiration Evaporation of water vapour from the surface of a plant.

trophic level A feeding level in a food chain or food web, e.g. producer, primary consumer.

tropism A growth response of a plant as a result of the environment.

turgid Plant cells that have a full vacuole and so the cytoplasm pushes against the cell wall, giving the plant structure and support.

turgor pressure The pressure of the cytoplasm inside a cell against the cell wall.

urea The substance produced in the liver from the breakdown of amino acids that are not needed in the body.

uterus Where a baby develops inside a mother.

vacuole A large sac found in the middle of many plant cells, containing cell sap.

vagina An elastic muscular tube where sperm is received from the penis during sexual intercourse.

valve Flaps in the heart, and in veins, that prevent the flow of blood in the wrong direction.

vascular bundle Tissue that forms the veins in plant roots, stems and leaves, containing xylem vessels and phloem cells.

vasoconstriction The narrowing (constriction) of blood vessels.

vasodilation The widening of blood vessels.

variety Members of a species with distinct characteristics in common, which can be inherited.

vein *(animal)* A blood vessel that carries blood towards the heart. *(plant)* See *vascular bundle*.

vena cava The largest human vein that delivers blood from the body to the right aorta.

ventilation Moving air into and out of the lungs.

ventricle One of two chambers of the heart that receive blood from the atria and pump it out through arteries.

villus Finger-like projection of the small intestine wall where absorption of digested food molecules occurs.

vitamin A nutrient needed by the body in tiny amounts to remain healthy, such as vitamins A, C and D.

voluntary Done consciously, after thought.

waste product A product of a chemical reaction that is not needed, such as oxygen in photosynthesis.

water A universal solvent made of hydrogen and oxygen.

water cycle How water cycles in different states between living organisms and the environment.

water potential The potential for a solution to take up more water molecules; it is 0 for pure water and has a negative value for solutions.

water potential gradient The difference in water potential between two regions, e.g. in a plant.

xylem vessel A tube formed from dead cells in the vascular bundles of a plant, which carries water and dissolved substances from the roots to the leaves and other parts of the plant.

zygote A fertilised egg, formed from the fusion of a male gamete and female gamete.

The answers given in this section have been written by the author(s) and are not taken from examination mark schemes.

SECTION 1 CHARACTERISTICS OF LIVING ORGANISMS

Life processes

Page 14

1. **a)** Any suitable answers for human, such as: movement – walking; respiration – combination of oxygen with glucose to release energy, carbon dioxide and water; sensitivity – vision; growth – increase in height; reproduction – having a baby; excretion – producing urine; nutrition – eating food.

   b) Any suitable answers for a specific animal, such as:
   movement – crawling; respiration – combination of oxygen with glucose to release energy, carbon dioxide and water; sensitivity – smell; growth – increase in length; reproduction – producing young; excretion – losing carbon dioxide through respiratory surface; nutrition – eating food.

   c) Any suitable answers for a plant, such as: movement – growing towards light; respiration – combination of oxygen with glucose to release energy, carbon dioxide and water; sensitivity – detecting direction of light; growth – increase in height; reproduction – producing seeds; excretion – diffusion of waste products out of leaf for photosynthesis (oxygen) and respiration (carbon dioxide); nutrition – taking in nutrients from soil and making glucose by photosynthesis.

2. Movement – to reach best place to get food or other conditions favourable for growth
   respiration – to release energy from food that can be used for all life processes
   sensitivity – to detect changes in the environment
   growth – to increase in size until large/mature enough for reproduction
   reproduction – to pass genes on to next generation
   excretion – to remove harmful substances from body
   nutrition – to take in substances needed by the body for growth and reproduction.

SECTION 2 CELLS

Cell structure

Page 24

1. **a)** Drawing should be drawn with thin, clear pencil lines, no crossing out, to show the outline of the cell in the photograph and the central shape.

   b) Diagram should be labelled to show nucleus, cytoplasm and cell membrane.

2. cell wall, large vacuole, chloroplast
3. **a)** chloroplast

   b) large vacuole

   c) cell wall.

Page 26

1. **a)** Lining some tubes in animal organs, such as the respiratory tract of humans; the cilia on the outside of the cells help move substances along inside the tubes.

   b) In blood; carry oxygen around attached to haemoglobin inside the cell.

   c) Near the tips of plant roots; have long cell extensions to increase surface area for absorption of materials into the root.

2. Sperm cells are small, and have a tail for movement. Mitochondria provide energy for movement of the tail, and the acrosome contains enzymes that digest the egg cell membrane so the sperm nucleus can enter the egg cell for fertilisation. Egg cells are large and contain a lot of cytoplasm to provide nutrients for the fertilised cell during the early stages of division.

Size of specimens

Page 28

1. 2 mm
2. If you are not using a suitable magnification for the specimen you are looking at, you may not be able to see what you want to. (It is most useful to start by focusing at a lower magnification and then moving up to the magnification you want to use.)
3. actual size $= \dfrac{2.5\text{mm}}{100}$

Diffusion

Page 31

1. Any answer that means the same as the following:

   net movement – the sum of movement in all the different directions possible

   diffusion – the sum of the movement of particles from an area of high concentration to an area of lower concentration in a solution or across a partially permeable membrane.

2. Passive, because no energy is provided by the cell for it to happen.
3. Only particles that are small enough to pass through the membrane can diffuse. Larger molecules cannot diffuse through the membrane.

Osmosis

Page 35

1. Any answer that means the same as the following: the net movement of water molecules from a region of their high concentration to a region of their lower concentration through a partially permeable membrane.
2. **a)** It is a passive movement of molecules as the result of a concentration gradient.

   b) Osmosis only considers the movement of water molecules; diffusion considers the solute molecules and may or may not involve a partially permeable membrane.

Water potential

Page 37

1. **EXTENDED** **a)** Not full of water.

   b) Full of water.

   c) The removal of water from a cell so that it shrinks in size (or the cell membrane surrounding the cytoplasm of a plant cell pulls away from the cell wall).

   d) The pressure caused by the water in the cytoplasm on the cell wall that prevents more water entering the cell.
2. **EXTENDED** The water potential of the cells inside the plant root is lower than the water potential of the soil water surrounding the root, so water moves down the water potential gradient into the root.
3. **EXTENDED** Diagram should show water molecules leaving the red blood cell as a result of osmosis and entering the solution. Labels should indicate a water potential gradient from the cell to the solution and indicate that the loss of water results in plasmolysis.

SECTION 3 BIOLOGICAL MOLECULES

Carbohydrates, proteins and lipids

Page 45

1. **a)** fatty acids and glycerol **b)** simple sugars **c)** amino acids
2. Protein is formed from amino acids, carbohydrates from simple sugars; carbohydrates are often made from one kind of simple sugar, proteins from many different kinds of amino acids.

Tests for food molecules

Page 47

1. **a) i)** A brick-red precipitate would form, because glucose is a reducing sugar. **ii)** The solution wouldn't change colour as there is no starch present.

   b) i) There would be no change in colour because sucrose and the starch in wheat flour are not glucose (reducing sugar). **ii)** The solution would turn blue–black because of the starch in flour.
2. Crush the walnut using a mortar and pestle, then:

   a) mix part with ethanol, decant the liquid and add water, if the mixture turns cloudy, then fat is present

   b) mix part with water to form a solution, add a few drops of biuret solution – if protein present, a blue ring forms at the surface, which disappears to form a purple solution.

SECTION 4 ENZYMES

Enzymes as catalysts

Page 53

1. A chemical that is found in living organisms and that changes the speed of a reaction.
2. A substrate is a molecule that an enzyme joins with at the start of a reaction. Substrate molecules are changed to product molecules during a reaction.

Enzyme action

Page 54

1. The sequence of amino acids in the amino acid chain determines the way the chain will fold up to make the three-dimensional structure of the protein.
2. **EXTENDED** The shape in an enzyme into which a substrate fits closely during a reaction.
3. **EXTENDED** Only a substrate with a shape that is complementary to the shape of the active site can fit it into it. So an enzyme can only work with a particular shape of substrate.

Enzymes and pH

Page 58

1. As temperature increases, the rate of the reaction will increase, up to a maximum point (the optimum) after which it decreases rapidly as the enzyme is denatured.
2. The optimum pH for pepsin is around pH 2, which is very acidic like the contents of the stomach. The optimum for trypsin is around pH 8, which is more alkaline like the contents of the small intestine. Each enzyme has an optimum pH that matches the environment in which they work, so that they act most efficiently there.

Page 59

1. a) **EXTENDED** The cooler molecules are, the slower they move. So the longer it takes for the enzyme and substrate molecules to bump into each other and the substrate to fit into the active site. Therefore, the cooler the temperature, the slower the rate of reaction.

   b) As temperature increases, the atoms in the enzyme vibrate more. This changes the shape of the active site, making it more difficult for the substrate to fit into the active site and so slowing down the rate of reaction. Eventually, the atoms vibrate so much that the shape of the active site is destroyed and the enzyme is denatured.

2. **EXTENDED** At a pH above and below the optimum of pH 2, the shape of the active site is changed as the interactions between the amino acids in the enzyme are affected by the pH. This makes it more difficult for the substrate to fit into the active site, so the rate of reaction slows down.

SECTION 5 PLANT NUTRITION

Photosynthesis

Page 66

1. $$\text{carbon dioxide} + \text{water} \xrightarrow[\text{light energy}]{\text{chlorophyll}} \text{glucose} + \text{oxygen}$$

2. Without light, photosynthesis cannot take place in plant cells.

3. a) **EXTENDED** $6CO_2 + 6H_2O \xrightarrow[\text{light energy}]{\text{chlorophyll}} C_6H_{12}O_6 + 6O_2$

   b) Labels should show: CO_2 from air, H_2O from soil water, $C_6H_{12}O_6$ used in cells for respiration or converted to other chemicals for use in cells, O_2 released into air if not needed in respiration.

4. **EXTENDED** Most organisms other than plants get their energy in chemical form from the food that they eat. That energy was originally converted from light energy to chemical energy during photosynthesis in a plant cell and then transferred as chemical energy along the food chain.

Page 68

1. Test the leaf of a variegated plant for starch. Starch is only produced in the green parts of the leaf, where there is chlorophyll, so only the green parts of the leaf photosynthesise.

2. Heat in a water bath, keeping the ethanol away from open flames such as from a Bunsen burner, because ethanol gives off flammable fumes.

3. Place one destarched plant in an atmosphere with no (or limited) carbon dioxide (due to potassium hydroxide) and one in an atmosphere high in carbon dioxide (due to carbon dioxide given off in a reaction between marble chips and dilute acid). Shine light on the plants. Test one leaf from each plant after several hours. Only the leaf in high carbon dioxide will have produced significant amounts of starch as a result of photosynthesis.

Page 70

1. a) **EXTENDED** As light increases, so rate of photosynthesis increases.

   b) As carbon dioxide increases, so rate of photosynthesis increases.

   c) As temperature increases, the rate of photosynthesis increases up to a maximum, after which it decreases rapidly.

2. a) **EXTENDED** As light increases, more energy is supplied to drive the process of photosynthesis.

   b) As carbon dioxide increases, so there is more reactant for the process.

   c) As temperature increases up to the maximum, the particles in the reaction including enzymes are moving faster and bump into each other more. Above the maximum, the rate of photosynthesis decreases because the enzymes that control the process start to become denatured.

Leaf structure

Page 72

1. Any four from: cuticle, epidermis, spongy mesophyll, palisade mesophyll, xylem.

2. **EXTENDED** Thin broad leaves, chlorophyll in cells, veins containing xylem tissue that transports water and mineral ions to the leaves and phloem tissue that takes products of photosynthesis to other parts of the plant, transparent epidermal cells, palisade cells tightly packed in a single layer near top of leaf, stomata to allow gases into and out of leaf, spongy mesophyll layer with large internal surface.

3. **EXTENDED** A large surface area helps to maximise the rate of diffusion, in this case diffusion of carbon dioxide into cells for photosynthesis and oxygen out of cells so that it can be released into the air.

4. **EXTENDED** It allows as much light as possible to pass through the epidermal cells to reach the palisade cells below, where there are chloroplasts.

Mineral requirements of plants

Page 73

1. Plants make their own foods and need to convert the carbohydrates made by photosynthesis into other substances, such as proteins, which contain additional elements.
2. a) Nitrogen is an essential element for making substances other than carbohydrates, such as proteins.
   b) Magnesium is needed to make chlorophyll, which is the green substance in plants.
3. a) **EXTENDED** Stunted growth: because without proteins, the plant cannot make new cells and will not grow well.
   b) Without enough magnesium the plant will not be able to make enough chlorophyll, so it will lose the green colour and become yellow. Any magnesium in the plant is transported to the new leaves, so that photosynthesis can continue there for making food for growth.

SECTION 6 ANIMAL NUTRITION

Diet

Page 83

1. carbohydrates, proteins and fats
2. Carbohydrates from pasta, rice, potato, bread, wheat flour; proteins from meat, pulses, milk products, nuts; fats from vegetable oils, butter, full-fat milk products, red meat.
3. vitamins, minerals, water and fibre
4. Vitamins and minerals are needed for maintaining the health of skin, blood, bones, etc. Water is needed to maintain the water potential of cells. Fibre is needed to help digested food to move easily through the alimentary canal.
5. **EXTENDED** Kwashiorkor is caused in young children by a diet low in protein. It results in swelling of the feet and abdomen, loss of muscle tissue, hair and teeth.

Page 85

1. **EXTENDED** Any answer along the lines of: different people need different amounts of energy every day; for example, active people need more than people who are seated for much of the day; men have a larger average body mass than women so will need more energy to support that extra tissue; some groups of people need more of a particular group of nutrients than others, e.g. pregnant women need additional iron.
2. **EXTENDED** Food that contains more energy than the body uses is converted into body fat, leading to obesity, which is associated with many health problems. A diet that is too low in energy leads to health problems as a result of low body weight.
3. a) **EXTENDED** Obesity is caused by a diet that contains too much energy, and is associated with many diseases.
   b) **EXTENDED** Starvation is a diet too low in energy and/or nutrients, leading to health problems from deficiency diseases or breakdown of muscle tissue for energy.
   c) **EXTENDED** Constipation is caused by too little fibre in the diet and may lead to diseases such as bowel cancer and diverticulitis.

Alimentary canal

Page 88

1. Sketch should show the following labels correctly attached to organs shown on the diagram:
   - mouth, where food is broken down by physical digestion (chewing) and amylase enzyme starts digestion of starch in food
   - oesophagus moves food from mouth to stomach by peristalsis
   - stomach, where churning mixes food with protease enzymes and acid to start digestion of protein molecules
   - small intestine, where alkaline bile neutralises the acid chyme and enzymes from pancreas complete digestion of proteins, lipids and carbohydrates, and where digested food molecules are absorbed into the body
   - large intestine, where water is absorbed from undigested food
   - rectum, where faeces are held until they are egested through the anus
   - liver, where bile is made and where some food molecules are assimilated
   - gall bladder, where bile is stored until needed
   - pancreas, where proteases, lipases and amylase are made, which pass to the small intestine.
2. Egestion is the removal of undigested food from the alimentary canal – food that has never crossed the intestine wall into the body. Excretion is the removal of waste substances that have been produced inside the body.
3. Peristalsis, caused by contraction of the circular muscles of the alimentary canal, followed by relaxation as the longitudinal muscles contract.

Mechanical digestion

Page 91

1. **EXTENDED** Chemical digestion uses chemicals (enzymes) to help break down large food molecules into smaller ones. Mechanical digestion is the chewing by the teeth to break large pieces of food into smaller ones before swallowing, or the breaking up of large fat droplets into smaller ones by bile.
2. Incisors have a flat blade shape for biting off food. Canines have a sharp point for holding food while other teeth chew off pieces. Premolars and molars have grinding surfaces for chewing.
3. Brushing removes particles of food caught in the teeth. Bacteria growing on these particles can release acids that destroy the tooth enamel, leading to tooth decay. So brushing prevents bacterial growth and tooth decay.
4. **EXTENDED** Bile helps to emulsify fats in food, breaking them up into much smaller droplets and creating a much larger surface area for lipase enzymes to act on.

Chemical digestion

Page 93

1. **EXTENDED** The digestive enzymes break down food molecules that are too large to cross the wall of the small intestine into smaller ones that can be absorbed across cell membranes and so enter the body. If we did not have enzymes, we would not be able to absorb many nutrients from our food.
2. **a)** **EXTENDED** amylase

   b) **EXTENDED** glucose
3. **a)** **EXTENDED** The acid increases stomach acidity, providing the right conditions for enzymes that digest food in the stomach.

   b) **EXTENDED** Bile neutralises the acidity of food from the stomach, providing the right conditions for enzymes that digest food in the small intestine. It also emulsifies fats, providing a larger surface area for lipase enzymes to work on.

Absorption of food

Page 95

1. The movement of digested food molecules across the alimentary canal (small intestine) wall into the body.
2. Small intestine and large intestine.
3. **EXTENDED** The larger the surface area, the more rapidly small molecules can be absorbed across the intestine wall into the body.
4. **EXTENDED** There are millions of villi on the surface of the intestine wall projecting into the alimentary canal. This greatly increases the surface area of the wall.
5. **EXTENDED** The capillaries provide a large blood supply to remove absorbed food molecules quickly, so maintaining a high concentration gradient for diffusion; lacteals in the villi carry absorbed lipid molecules away to the rest of the body.

SECTION 7 TRANSPORT

Xylem and phloem

Page 104

1. In vascular bundles that form veins throughout the roots, stems and leaves.
2. Xylem vessels are long continuous tubes formed from dead cells, which allow water and dissolved substances to pass easily through the plant.
3. Phloem cells link together to form continuous phloem tissue in the vascular bundles. They carry dissolved food materials, such as sucrose and amino acids, from the leaves where they are formed to other parts of the plants that use them for life processes or where they will be stored.

Water uptake

Page 106

1. It enters through the root hair cells, moves through the root cortical cells to the xylem in the centre of the root. It moves through the xylem up the stem and into the leaves. In the leaves, it moves out of the xylem into the spongy mesophyll cells.
2. Place a stem of a plant in water containing food colouring. The colour will travel through the xylem with the water, and show where the xylem is in the stem, leaves and flowers.
3. **a)** osmosis, **b)** active transport
4. Diagram should include annotations like the following, at the appropriate point: soil water has higher concentration of water molecules than cytoplasm of cells in the root; water molecules enter root hair cells by osmosis; water molecules pass from cell to neighbouring cell by osmosis until they reach the xylem.

Transpiration

Page 110

1. Evaporation from the surfaces of a plant, particularly from the stomata of a leaf into the air.
2. Diagram should include annotations like the following, at the appropriate point: water molecules evaporate from surfaces of spongy mesophyll cells into air spaces; water molecules from air spaces move into and out through stomata into the air – diffusion (net movement) usually from inside leaf to outside; osmosis causes water molecules to move from xylem into neighbouring leaf cells, and then from cell to cell until they reach a photosynthesising cell or a spongy mesophyll cell; transpiration is the evaporation of water from a leaf.
3. Closing stomata reduces diffusion of water molecules out of the leaf. At night, oxygen is not needed for photosynthesis, so keeping stomata open would lose water unnecessarily.
4. **a)** When temperature is higher, particles move faster, so water molecules will diffuse out of the leaf more quickly.

   b) When air humidity is high, there is a high concentration of water molecules in the air. So more water particles will move from the air through the stomata into the leaf while water particles are moving out of the leaf into the air. This means the rate of diffusion will be lower.
5. **EXTENDED** Cohesion of water molecules means they stick to each other. So as water moves out of the xylem in the leaves, down its potential gradient into the spongy mesophyll cells, more water molecules are drawn up the xylem tube through the plant through cohesion of water. This causes a water potential gradient between the root cortical cells and the xylem in the root, drawing more water into the xylem.

Translocation

Page 111

1. **EXTENDED** phloem
2. **EXTENDED** sucrose and amino acids

Circulation in mammals

Page 115

1. To pump blood around the body.
2. Valves in the heart and veins.
3. **EXTENDED** Blood passes twice through the heart for every once round the body – there are effectively two separate circulations of blood from the heart.
4. **EXTENDED** The pressure in the two circulations can be different, so the high blood pressure needed to get blood through all of the body doesn't damage the delicate capillaries in lung tissue.

Heart

Page 117

1. left atrium, right atrium, left ventricle, right ventricle
2. Arteries carry blood away from the heart; veins carry blood towards the heart.
3. **EXTENDED** vena cava, right atrium, right ventricle, pulmonary artery, pulmonary vein, left atrium, left ventricle, aorta

Page 119

1. Resting heart rate varies widely due to many factors, including age, health and fitness, so a single value for the average is too limited.
2. As level of activity increases, so heart rate increases.
3. **EXTENDED** Heart rate increases with exercise so the blood can circulate faster round the body, delivering oxygen and glucose to muscle cells for the increased rate of respiration to generate the energy needed for contraction. It also removes waste carbon dioxide from muscle tissue more rapidly to prevent it building up and affecting cells.

Page 121

1. To supply the oxygen and glucose needed for the heart muscle cells to respire and to remove waste carbon dioxide.
2. **EXTENDED** smoking, diet containing a lot of saturated fat, stress, genetic factors
3. **EXTENDED** Eat a diet that is relatively low in saturated fat, don't smoke and try to control stress and the effects that it has on behaviour.

Blood vessels

Page 124

1. **a)** renal arteries, **b)** aorta, **c)** pulmonary veins
2. Arteries are large vessels with thick, elastic muscular walls; capillaries are tiny blood vessels with very thin walls that are often only one cell thick; veins are large vessels with a large lumen and valves to prevent backflow of blood.
3. **EXTENDED** The walls stretch as blood enters them, and slowly relax as the blood flows through, balancing out the pressure so that the change in pressure is reduced.

Blood

Page 127

1.

Blood component	Function
plasma	carries dissolved substances, such as carbon dioxide, glucose, urea and hormones; also transfers heat energy from warmer to cooler parts of the body
red blood cell	carries oxygen
white blood cell	protects against infection
platelet	causes blood clots to form when a blood vessel is damaged

2. The biconcave disc shape increases surface-area-to-volume ratio, so rate of diffusion of oxygen into and out of cell is maximised. Haemoglobin inside the cell binds with oxygen when oxygen concentration is high and releases oxygen when oxygen concentration is low. The cell has no nucleus, so there is as much room as possible for haemoglobin. The cell has a flexible shape so can squeeze through the smallest capillaries and reach all tissues.
3. Some white blood cells engulf pathogens inside the body and destroy them. Others produce antibodies that attack pathogens.

SECTION 8 GAS EXCHANGE AND RESPIRATION

The human respiratory system

Page 138

1. Exchange of gases between the body and the environment is by diffusion. Organisms need plenty of oxygen for respiration to provide energy for all life processes, and need to get rid of the waste carbon dioxide. So a rapid rate of diffusion supports a higher rate of respiration and all the other processes in the body.
2. The trachea carries air from the mouth down to the lungs; the bronchi (the two large divisions of the trachea as it reaches the lungs) are supported with rings of cartilage to prevent collapse during breathing; the bronchioles (the fine tubes in the lungs) carry the air to the alveoli; the alveoli (the bulges of the air sac) have a large surface area and are very thin for efficient diffusion of gases.
3. Sketch similar to Fig. 8.4, with annotations showing: thin lining of alveolar wall and wall of capillary allows rapid diffusion; high concentration gradients for gases between blood and air in alveolus due to continuous blood flow through capillary and ventilation of alveolus (lungs); large area of contact between capillary and alveolus, maximising area over which diffusion can occur.
4. **EXTENDED** The mucus traps particles and microorganisms that are in the air breathed in, and the cilia move the mucus and anything trapped in it up out of the lungs to the throat, where it can be swallowed. This protects the lungs from damage and infection.

Investigating the effect of exercise on breathing

Page 141

1. The percentage of oxygen is less in exhaled air than inhaled air. The percentage of carbon dioxide is greater in exhaled air than inhaled air. The percentage of water vapour is higher in exhaled air than inhaled air.
2. As level of exercise increases, rate and depth of breathing increase.
3. **EXTENDED** There is less oxygen in expired air than inspired air because oxygen in the body is used for respiration. There is more carbon dioxide in exhaled air than inhaled air because the body produces carbon dioxide in respiration. There is more water vapour in exhaled air than inhaled air because water molecules evaporate from the surface of the alveoli due to warmth of the body.
4. **EXTENDED** More exercise means more carbon dioxide is produced from an increased rate of respiration. Carbon dioxide is a soluble acidic gas so causes the body tissues and blood to become more acidic. A change in pH can affect many enzymes and so affect the rate at which life processes are carried out in the body. Slowing down the rate of life processes may harm the body.

Aerobic respiration

Page 147

1. **a)**, **b)** and **c)**:

   glucose (*from digested food from alimentary canal*) + oxygen (*from air via lungs*) ⟶ carbon dioxide (*excreted through lungs*) + water (*used in cells or excreted through kidneys*) (+ energy (*transferred to other chemicals in cell processes*))

   d) glucose replaced by fats from hump, and water from respiration is retained
2. inside cells
3. Any three from: muscles cells for contraction, synthesis of new molecules, such as proteins, for growth, active transport across cell membranes, passage of nerve impulses, maintenance of core body temperature.

4. **EXTENDED** $C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$

Anaerobic respiration

Page 149

1. **EXTENDED** During vigorous exercise, they may not be able to get enough oxygen from the blood for all the energy they need for contracting. So the additional energy comes from anaerobic respiration.
2. **EXTENDED** Similarities: use glucose as substrate, produce energy, don't need oxygen. Differences: animals produce lactic acid, plants produce ethanol and carbon dioxide.
3. **EXTENDED** The amount of energy released from a mole of glucose molecules is much greater during aerobic respiration (c. 2900 kJ) than in anaerobic respiration (c. 150 kJ) in muscle cells.
4. **EXTENDED** Carbon dioxide is released by anaerobic respiration of glucose by yeast. Bubbles of the gas trapped in the dough makes it rise. Warmth speeds up the rate of respiration.

SECTION 9 CO-ORDINATION AND RESPONSE

The human nervous system

Page 156

1. The ability to detect and respond to changes in the external environment and internal conditions of the body.
2. A receptor detects a change in the environment, which is the stimulus. This causes a response from an effector in the body.
3. muscles and glands
4. Sensory neurones have long dendrons and axons that link the sense organ with the central nervous system.

   Relay neurones are short neurones with many dendrites, found in the central nervous system, that link sensory neurones to motor neurones or other relay neurones.

   Motor neurones have many dendrites to link with relay neurones and end on the effector, such as a muscle.

Page 158

1. A simple response of receptor > nerve > spinal cord > nerve > effector, which does not usually include the brain.
2. Reflex responses are very fast, which makes it possible to respond to a stimulus very quickly. Reflex responses are usually important in survival, e.g. to protect you from touching something dangerous, or blinking to protect the eye if something comes toward it.
3. **EXTENDED** A voluntary action is one that is consciously chosen (i.e. thought about), such as choosing what to eat. An involuntary reaction is one that is done unconsciously, such as blinking when something comes toward the eye.

Human sense organs

Page 162

1. **EXTENDED** **a)** The cornea is transparent, so light passes through it easily into the eye.
   - **b)** The pupil is a hole surrounded by the iris that lets light pass through to the back of the eye.
   - **c)** The retina contains the light-sensitive cells that respond to light. The retina is also very dark, to absorb as much light as possible.
2. **EXTENDED** As light intensity increases, the pupil gets smaller, reducing the amount of light that can enter the eye. As light intensity decreases, the pupil gets larger, increasing the amount of light that can enter the eye.

   Pupil constriction in bright light happens because the radial muscle in the iris relaxes and the circular muscle contracts. Pupil dilation in dim light happens because the radial muscle in the iris contracts and the circular muscle relaxes.

Page 163

1. **EXTENDED** Light entering the eye from a near object needs to be refracted more than light from a distant object in order to focus it on the retina. The ciliary muscles contract, which reduces the tension on the ligaments that are attached to the lens. This allows the lens to become thicker and more rounded, which increases its focusing power.
2. **EXTENDED** For light from a distant object to be focused on the retina, the lens needs to be thin. So the ciliary muscles relax and the suspensory ligaments pull harder on the lens, causing it to flatten.

Hormones in humans

Page 168

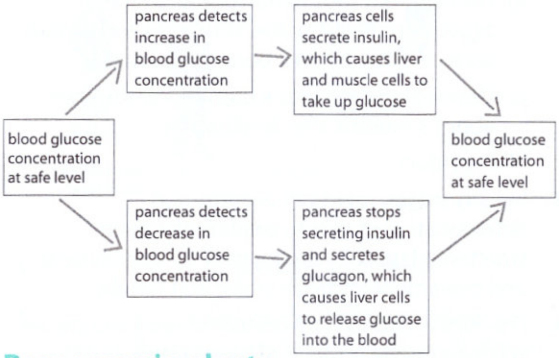
1. **a)** A chemical messenger in the body that produces a change in the way some cells work.
   - **b)** A gland that secretes hormones.
   - **c)** An organ that contains cells that are affected by hormones.
2. When faced with attack, or when suddenly frightened.
3. It prepares the body for action by increasing the amount of oxygen and glucose delivered to muscle cells for rapid respiration, and improving vision.

4. **EXTENDED** The nervous system produces fast, short-term responses as a result of electrical impulses that pass along neurones between the receptor, central nervous system and effector. The hormonal system produces longer-term responses that are slower, by the secretion of chemical hormones from endocrine glands into the blood to travel to effector organs, where they cause a change in activity.

Homeostasis in humans

Page 174

1. The maintenance of conditions inside the body within limits that allow cells to work efficiently.
2. Control of core body temperature (other answers are possible).
3. Skin blood vessels dilate when the core body temperature is too high. This allows heat energy carried by the blood to reach the skin surface more easily and so be transferred to the environment more rapidly. Skin blood vessels constrict when the core body temperature falls too low. This reduces blood flow to near the skin's surface, so heat energy cannot be transferred as easily to the skin surface and so cannot be transferred to the environment as quickly. This keeps more heat energy within the body.
4. **EXTENDED** When a change in a stimulus causes a control centre to trigger the opposite change in response, so keeping a condition within limits.
5. **EXTENDED**


blood glucose concentration at safe level
pancreas detects increase in blood glucose concentration
pancreas cells secrete insulin, which causes liver and muscle cells to take up glucose
pancreas detects decrease in blood glucose concentration
pancreas stops secreting insulin and secretes glucagon, which causes liver cells to release glucose into the blood
blood glucose concentration at safe level

Responses in plants

Page 181

1. A growth response of a plant to a stimulus.
2. **a)** Shoots grow towards light.
   b) Roots grow in the direction of the force of gravity.
3. **EXTENDED** Auxin is produced in the tip of the growing shoot and diffuses down the shoot. Auxin on the bright/light side of the shoot moves across the shoot to the darker side as it diffuses down the shoot. Cells on the dark side of the shoot elongate more than the cells on the light side of the shoot, so the shoot starts to bend as it grows so that the tip is pointing towards the light.
4. **EXTENDED** Auxins are absorbed into the leaves of broad-leaved weed plants more than into the leaves of grass-type crop plants. They cause the weed plants to grow so rapidly that they cannot sustain growth and die, leaving more space for the crop plants.

SECTION 10 REPRODUCTION

Asexual reproduction

Page 188

1. Reproduction without the fusion of gametes, using a cell from only one parent.
2. Binary fission is where the genetic material is copied and the cell splits in half. Only one cell is involved and there is no fusion of parent cells before division.
3. **EXTENDED** Advantages: no need for fertilisation, so reproduction faster and easier; if conditions remain stable, all new individuals will grow as well as the parent plant. Disadvantages: no genetic variation between plants, so if conditions change/the parent plant is susceptible to a particular disease, then all plants will do badly; this increases the risk that the plants in that area will all die.

Sexual Reproduction

Page 189

1. **a)** The fusion of a male gamete and a female gamete to produce a zygote.
   b) The production of offspring from two parents as a result of fertilisation.
2. **a)** **EXTENDED** a sex cell or gamete such as a sperm, male gamete in a pollen grain, or an egg cell
   b) a zygote, or fertilised egg cell
3. **EXTENDED** Advantage: produces individuals with new variations of genetic material that increase the chance of survival when conditions change. Disadvantage: variation in offspring may also result in many offspring being less well adapted to environmental conditions than parent plants and so producing less harvest.

Flowering plants

Page 194

1. Stigma, where pollen grains attach; style, which supports the stigma; ovary, which surrounds and protects the ovule, inside which is the female gamete.
2. Stamen, which includes an anther that contains pollen grains, inside which are the male gametes; filament, which holds the anther above the flower to help with shedding of pollen.

Page 197

1. Pollination is the transfer of pollen from a stamen to a stigma. Fertilisation is the fusion of the male gamete with the female gamete to form a zygote.
2. **EXTENDED** Any three from: wind-pollinated flowers usually small, no colour (white), make masses of lightweight pollen. Insect-pollinated plants usually large, may be brightly coloured, produce nectar and sometimes scent, make small amounts of larger pollen grains.
3. a) **EXTENDED** Can make less pollen; less waste of pollen as insects more likely to deliver pollen to flower than random distribution in wind.

   b) **EXTENDED** If the insect species die out, the plant will not get pollinated.

Page 200

1. When the embryo in a seed starts to grow, splitting the seed coat and increasing in size and complexity.
2. a) Seeds need a supply of oxygen for growth, although they may be able to start germination using anaerobic respiration.

   b) Seeds need water for germination and will not germinate in dry soil.

   c) Seeds need warmth for germination, although the amount of warmth they need may depend on where they naturally grow. Seeds from plants that live in colder areas may need a period of deep cold before they will germinate. Seeds from plants that live in areas prone to fire may not germinate until after a fire.

Human reproduction

Page 206

1. Sketch should be similar to Fig. 10.20. Labels and annotations as follows:
   - testes, where sperm (male gametes) are produced
   - sperm duct, which carries sperm to urethra
   - prostate gland and seminal vesicles, which produce liquid in which sperm swim
   - penis, which when erect delivers sperm into vagina of female
   - urethra, the tube that carries sperm from sperm ducts to outside the body.
2. Sketch should be similar to Fig. 10.21. Labels and annotations as follows:
   - ovaries, where egg cells form
   - oviducts, which carry the eggs to the uterus and where fertilisation by sperm takes place
   - uterus, where embryo implants into lining and fetus develops
   - cervix, base of uterus where sperm are deposited during sexual intercourse
   - vagina, where penis is inserted during sexual intercourse.
3. **EXTENDED**

	Egg cell	Sperm cell
size	very large, 0.2 mm diameter	very small, 45 µm long
numbers	thousands in ovary but usually only one released each month	>100 million produced each day
mobility	unable to move on its own	self-propelling with tail

Page 208

1. a) The cell produced by fusion of a male gamete and female gamete.

   b) Formed from the division of cells in the zygote – until distinctive structures are obvious, such as limbs, when it becomes a fetus.

   c) Developing baby in the uterus (womb), from about 3 months after fertilisation.
2. In an oviduct.
3. In early stages, rapid cell division, and differentiation of cells to produce the main structures; later, development of nervous system and movement; increase in size and weight.
4. Provides nutrients from mother's blood and carries waste to mother's blood to be excreted.

Page 209

1. A disease that is transmitted in body fluids during sexual intercourse.
2. Through sexual body fluids during sexual intercourse; via blood through cuts or sharing of needles for injecting drugs; across the placenta from mother to fetus; through milk from mother to baby when breast-feeding.

3. **EXTENDED** The virus attacks the immune system, reducing the ability of the body to fight off other infections. This leads to AIDS.

4. **EXTENDED** Only have intercourse with a partner who is not infected with HIV; use barrier methods such as condoms or femidoms during intercourse.

SECTION 11 INHERITANCE

Chromosomes and genes

Page 216

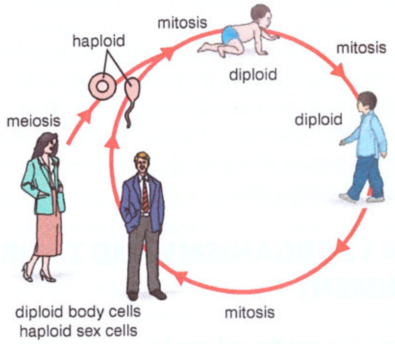
1. gene, chromosome, nucleus, cell
2. A gene codes for a protein or characteristic; an allele is one form of the gene coding for a variation in the protein or characteristic. Any suitable example, e.g. gene for eye colour, allele for blue eye colour or brown eye colour.
3. The passing on of inherited characteristics from one generation to the next due to the passing on of genes that code for those characteristics.

Cell division

Page 219

1. **a)** mitosis

   b) It produces cells that are identical.

2. 

3. **EXTENDED** **a)** meioisis **b)** mitosis

4. **EXTENDED** Meiosis produces non-identical cells, so there is variety in the gamete cells. When the gamete cells fuse, this will mean that the offspring will vary from each other.

Monohybrid inheritance

Page 223

1. **a)** The characteristic expressed in the phenotype when the organism has only one allele of that form.

   b) The characteristic expressed in the phenotype when both genes in the genotype are the alleles for this form.

   c) Having two identical copies of that allele for a particular gene.

   d) Having different alleles for a particular gene.

2. **a)** 2 **b)** 1 **c)** 2

3. **EXTENDED** 38: because the body cell contains two copies of each chromosome

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1. The inheritance of a characteristic produced by one gene.
2. Genotype (the alleles in the chromosomes) BB, phenotype (what the organism looks like) brown; genotype Bb, phenotype brown (because the brown allele is dominant); genotype bb, phenotype black (because the organism doesn't have the brown allele).
3. **a)** The answer may be presented as a full layout diagram or a Punnett square, showing the adult genotypes and phenotypes (male BB brown and female bb black), the possible gametes produced (male B and B, female b and b), genotypes and phenotypes of possible offspring (BB brown, Bb brown, Bb brown, bb black).

   b) This cross produces a theoretical probability of one black rabbit for every three brown rabbits, a ratio of 1 : 3, probability of 1 in 4 or 25%.

Page 228

1. So that, when the plants were bred together, the results in the offspring were not confused by a mix of alleles in one or both of the parents.

2. Random variation is possible in the results. So the larger the sample, the more likely that any random variation will be averaged out.

3. He removed the stamens from every flower, so that pollen could not be transferred by insect. He also covered each flower after he had hand-pollinated it, so that other pollen could not get to the stigma.

4. Any characteristic may be used, with alleles appropriately designated with capital letter for dominant and lower-case letter for recessive allele. Parents used should show one with phenotype of dominant allele, homozygous, e.g. BB, and one parent with phenotype of recessive allele, i.e. bb. First cross will produce all individuals with phenotype of dominant allele but heterozygous in genotype, i.e. Bb. Crossing of these individuals will produce characteristic 1 BB : 2 Bb : 1 bb in genotype and 3 dominant characteristic to 1 recessive characteristic in next generation.

5. If Mendel had not been as thorough about his method, then his results would not have been as clear and predictable. So he would not have been able to have drawn clear and repeatable conclusions about the way characteristics are inherited in pea plants.

Variation and selection

Page 232

1. All the differences between individuals of the same species.
2. Discontinuous, e.g. gender or tongue-rolling; continuous, e.g. height or weight.
3. **EXTENDED** Discontinuous caused by alleles in genes, because there is a limited number of alleles for a gene that produce each different variation of the characteristic. Continuous caused by genes and environment because environmental factors affect the variation produced by genes, producing a range of types.

Page 233

1. **EXTENDED** A change in the genetic code that produces a new allele which results in a different form of a characteristic.
2. **EXTENDED** Ionising radiation, such as ultraviolet radiation, X rays or gamma rays; chemical mutagens such as the chemicals in tobacco smoke.

Page 237

1. Answer along the lines of: the influence of the environment on a characteristic, such that some variations of the characteristic are more successful at producing offspring than others and pass on their genes to the next generation.
2. a) If the individuals in a population are not all the same (there is variation), natural selection will favour some over others.
   b) If there is competition between the variations, only those that are better adapted will be fit and healthy enough to produce offspring and pass on their genes.
   c) Individuals with a particular variation of an adaptive feature may be more likely to survive and reproduce than individuals with other variations. So they are more likely to produce offspring that carry their alleles, and so those alleles will become more common in the next generation.
3. **EXTENDED** As the better-adapted individuals contribute more offspring to the next generation than those that are less well adapted, more individuals will have the alleles for the better adaptations. This means that the individuals in the next generation will be better suited to their environment than their parents.
4. **EXTENDED** Diagram should show the following: person infected with bacteria > bacteria grow in number inside patient > treatment of patient with antibiotics kills off least-resistant bacteria but most-resistant bacteria survive > some of these bacteria escape into the environment from the patient and infect another person > the same antibiotic cannot be used on that patient as the bacteria are resistant.

Page 239

1. People who want to develop new varieties of plants and animals that have economic importance (earning more money for the breeder).
2. Any two suitable examples, e.g. increased meat production of beef cattle, large eggs produced by chickens, unusual flower colours, crops that produce large amounts of grain.
3. Parent organisms with desirable characteristics are selected and bred together. Offspring with the best combination of characteristics are selected and then bred together. The process is repeated over many generations to produce a number of individuals that all exhibit the desired characteristics.
4. **EXTENDED** Natural selection is selection by the environment for features that are best adapted to the conditions in that environment. Selective breeding is the selection of features by people of plants and animals that the people think are most useful or most attractive.

SECTION 12 ORGANISMS AND THEIR ENVIRONMENT

Food chains and food webs

Page 250

1. Producer: an organism that produces its own food from simpler materials, e.g. plants making carbohydrates in photosynthesis.

   Consumer: an organism that gets its food from eating other organisms, e.g. animal.

   Herbivore: an animal that eats plants.

   Carnivore: an animal that eats other animals.

   Decomposer: an organism that gets its food from dead plants and animals or waste material, such as some fungi and bacteria.

2. Ecosystem: a unit containing all of the organisms and their environment interacting together in a given area (e.g. a lake).

   Trophic level: the feeding level of an organism within a food chain or food web.
3. The Sun provides light energy, transferred as chemical energy to build plant tissue, which is then transferred as chemical energy through all other organisms in the ecosystem.
4. A food chain shows the relationship between one producer, one herbivore, the carnivore that eats the herbivore, etc.

   A food web shows the feeding relationships between all the organisms living in an area.
5. **a)** Food webs help us to understand the relationship between organisms in an area, and can help us predict what might happen to the organisms as a result of a change to the ecosystem.

   b) It can be difficult to organise the information in a food web because some organisms feed at many trophic levels, and it may not be possible to include all organisms (e.g. decomposers) on a food web because of space for the drawing.

Page 253

1. **EXTENDED** Energy in light from Sun (gain) > some reflected, some passes straight through, some wrong wavelength (losses) > energy in light transferred to chemical substances during photosynthesis > energy transferred to environment from photosynthetic reactions and from respiration by heating (losses) > energy stored in plant biomass.
2. **EXTENDED** Energy stored in food (gain) > energy in undigested food transferred to environment in faeces (loss) > energy stored in absorbed food molecules transferred to energy in waste products such as urea in urine and transferred to the environment (loss) > energy released in respiration transferred by heating to environment (loss) > energy stored in animal biomass.
3. **EXTENDED** Not all the energy gained is stored in new tissue in the organism. When the next trophic level feeds on the previous level, only the energy stored in the body tissue is available to it.

SECTION 13 HUMAN INFLUENCES ON ECOSYSTEMS

Deforestation

Page 263

1. **a)** Respiration releases carbon dioxide into the atmosphere from the breakdown of complex carbon compounds inside organisms.

   b) Photosynthesis fixes/converts carbon dioxide from the atmosphere into complex carbon compounds in plant tissue.

   c) Decomposition decays/breaks down dead plant and animal tissue by decomposers, releasing carbon dioxide into the atmosphere during respiration.
2. **a)** carbon dioxide, **b)** complex carbon compounds, **c)** complex carbon compounds
3. **EXTENDED** Combustion increases the carbon dioxide concentration in the atmosphere more rapidly than natural processes such as respiration. Deforestation removes trees, so this reduces the amount of oxygen taken from the atmosphere for photosynthesis and increases the amount of carbon dioxide released if the forest is burned. So this can rapidly change the oxygen/carbon dioxide balance in the atmosphere near the forest.

Page 264

1. Pollution by chemicals including oil or discarded plastic.
2. **a)** **EXTENDED** The destruction/cutting down of large areas of forest and woodland.

   b) The washing away of soil by heavy rainfall.

   c) When soluble nutrients dissolve in soil water and soak away deep into the ground.
3. **a)** **EXTENDED** Changes the amount of water transferred from soil to air through transpiration, so more water remains in soil and enters rivers.

   b) Soil washed away and nutrients leached from soil by increased water flow through ground, so decreasing soil fertility.

   c) Increases carbon dioxide concentration as less carbon dioxide taken from air through photosynthesis and stored as wood.

Water pollution

Page 266

1. They take a very long time to break down and they may leak poisonous chemicals into ground water, which can leak away into water systems.
2. The plastics cause problems for wildlife in the oceans that eat them by accident, or become entangled in them.

Page 270

1. Any three such as: industrial chemical release, untreated sewage, fertilisers.
2. Poisoning of the water by toxic chemicals.
3. The addition of nutrients to water.

4. Run-off of fertiliser into water as a result of heavy rainfall; leaching of soluble nutrients in fertiliser through soil into water systems.
5. Eutrophication leads to the rapid growth of algae and other microorganisms, which remove large amounts of oxygen from the water for respiration. This does not leave enough oxygen in the water for the fish, so they die.
6. **EXTENDED** Sewage added to water > adds nutrients to water = eutrophication > plant and microorganism growth rate increases > respiration rate of microorganisms increases, removing dissolved oxygen from water > less dissolved oxygen for other organisms, which die = water pollution.

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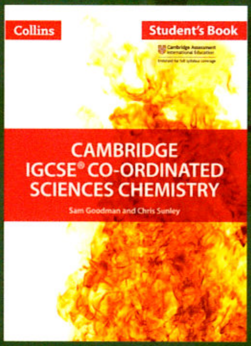

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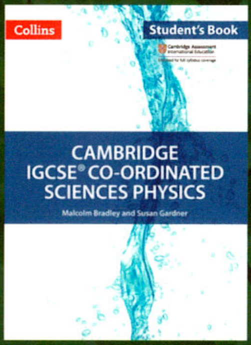

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